

A Climate of Inequality: Evaluating Re-emerging Malaria Risk among Vulnerable Immigrant
Populations in the Greater Toronto Area

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Submitted: July 31, 2014

A Major Paper submitted to the Faculty of Environmental Studies in partial fulfillment of the
requirements for the degree of Master in Environmental Studies,

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Abstract

The impacts of climate change are expected to affect certain groups disproportionately, based on the degree of inequality of social and material resources as defined by the social determinants of health (SDOH) model. One of these predicted impacts includes changes in the incidence and distribution of certain infectious diseases. In southern Ontario, this may include local sporadic outbreaks of malaria. Through travel and immigration, malaria already exists in the Greater Toronto Area (GTA) as an imported disease. Although local transmission does not occur within our current context, endemic malaria was present during the 18th and 19th centuries in southern Ontario. As such, malaria as a disease and as a cultural feature has significant presence within this region's past, its present, and possibly its future. The degree to which malaria already poses a health threat within the urban setting of the GTA, and how this may be implicated within a future climate change scenario forms the basis of this paper's investigation.

Three temporal scales (past, present, and future) were explored using various disciplines to understand the scope of both imported and potential locally-transmitted malaria. The main goals were to identify who are the vulnerable groups within the GTA and why, to explore how these themes align with historical realities of malaria in this region, and to gauge potential future vulnerability based on intersections between climatic projections and transmission requirements. These topics were investigated through literature review and through interviews with several local infectious disease specialists and health policy officials.

With regard to imported malaria, many inadequacies were recognized with respect to Canada's public health system regarding underreporting, surveillance, and disease management.

Vulnerable immigrant groups were identified based on their likelihood of travelling to or immigrating from malaria-endemic regions, an overall lack of connectivity with the public health system, high rates of malaria in countries of origin, and, less directly, a disproportionate burden of TB and HIV/AIDS, a high risk of poverty, experiences of racialization, and a lack of power and influence. These circumstances have both immediate and long-term effects on health and well-being, accounting for an increased risk of exposure to malaria infection abroad, as well as determining the severity of infection. Although several groups were identified, multiple-generation south Asian and African immigrants were considered to be particularly high-risk. Historical parallels drawn between past and present susceptible immigrant groups revealed similarities of social and economic disparity and the consequent poor health outcomes. Finally, an exploration of municipal, provincial, and national literature on infectious disease generally and malaria specifically revealed certain barriers to positive social change. Most prominently, a stubborn adherence to the biomedical focus of disease within policy recommendations, associated with reactive measures such as public education and surveillance, were found to undermine the saliency of the SDOH within malaria discourse. This political and economic setting, perhaps irrespective of climate change, may further deepen existing health inequalities felt by vulnerable groups, thus providing a compelling case for the application of the SDOH as an explanatory model within all considerations of health, including infectious disease.

Acknowledgements

No piece of work is every truly accomplished alone, but rather, is the cumulative effort of many diverse sources. As such, I would like to extend my deepest gratitude to the following individuals and groups as without their contribution, this work could never have been realized. First of all, I would like to thank my supervisor, Dennis Raphael, who took me on as a supervisee at very short notice. Your work has truly provided the foundation and inspiration for my research goals here at York University and beyond. To Ray Rogers, a fellow Scotian and my mentor, with every exchange you have granted me guidance and encouragement. Thank you so much for going above and beyond in your duties as my advisor, and for adamantly believing in me and my work. To Sarah Flicker, thank you for sparking my interest in the social determinants of health to begin with, a theme which has embodied this work, refuses to leave my head, and which I plan to carry out throughout my career. To the Faculty of Environmental Studies and the Office of Student and Academic Services, thank you for the outstanding administrative and financial support, Peggy McGrath, Kristal Ramsay, and Joseph Cesario in particular. I would also like to thank the donors of the Mark Nawrot Memorial Award for the timely financial leg up. To my fellow students in both Environmental Studies and Health Studies, thank you for struggling alongside me these past two years, and for motivating me to press harder and aim higher. I would also like to extend my deepest gratitude to all the interview participants. Your time, effort, and contributions were invaluable to this work and to my own research process. I also express infinite love and appreciation to Nayeem Ashraf for listening tirelessly to my rants on the social determinants of health, and for believing in me even when I was not able to. To my mother who has been my editor-in-chief and most reliable advisor, and has read and critiqued every last word I have written, thank you for spending countless hours contributing to this beast of a paper. Last but certainly not least, to all my friends and family, thank you for the indispensable moral support, without which Toronto would have surely swallowed me up.

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Foreword

The concept that truly sparked the inspiration for this paper, as well as the direction of my entire Master of Environmental Studies degree, was gaining an awareness of the social determinants of health, by means of a Health and Environment class taken in my first year. A concept with which I was previously unfamiliar until the beginning of this two year journey, the social determinants model of health helped me to not only question my previous notions of ‘what is health’, but also opened my eyes to how health is attached to everything around us, from income, to race, to power and influence. I now saw health not as an isolated concept limited to the fields of physiology, medicine, and so on, but as something that permeates into every facet of our lives.

Moreover, once I learned of the issues of inequality that define health in Toronto and the Greater Toronto Area, I had no other option but to pursue this track in my degree. Linking this with a passion for environmental history and a strong interest in infectious diseases and parasites (by-products of my undergraduate environmental science degree), I was inspired to research a topic that was truly multi-disciplinary, and set within the fascinating urban setting that has now become my home.

When using the social determinants of health as a framework, exploring each facet of a health issue can be exhausting and one may feel they are delving into an expanding system of relevance which branches off ad infinitum. The ability of knowing where to stop requires significant insight and experience, as well as confidence in one’s self. I have by no means mastered this ability, but this research process has allowed for significant honing of this skill. I also learned the very important lesson of accountability, as an academic and as a researcher. Maintaining these priorities, I was able to pull together three seemingly diverse themes (social determinants of health, environmental history, and climate-sensitive diseases), the three

components of my Area of Concentration, in a way that, I hope, will be reflective as well as having practical applications. This paper has allowed me to explore how malaria, a topic deeply seated within a medical context, could nevertheless be considered within a diversity of other discourses as well, such as history, socioeconomics, and health and climate policy. Through this process, I came to realize that the social determinants of health model could provide the grounds for significant positive social change for a health issue as specific as malaria, but even more so, it is a way of viewing the world as a community, rather than a collection of individuals. This focus will become all the more urgent as we face increasingly rapid changes both in demographics and in climate.

Chapter 1

Introduction

In the summer of 1828, the sickness in Upper Canada raged like a *plague*; all along the banks of the lakes, nothing but languid fevers; and at the Rideau Canal few could work with *fever* and *ague*; at *Jones's Falls* and *Kingston Mills*, no one was able to carry a draught of water to a friend; doctors and all were laid down together. And people take a long time to recover amid these hot swamps; it is not two or three weeks ill, and then up and well again, but so many months. (MacTaggart, 1829, p. 21)

Malaria is often considered an exotic, tropical disease that affects its unfortunate victims in nations far away, nations that could not be more different than the largest urban centre in one of the world's most progressive and industrialized nations, the Greater Toronto Area (GTA). That is why MacTaggart's quote, above, may come as a surprise to many. It is a relatively unknown fact that malaria was at one time endemic to the region of southern Ontario. However, as much as it is a part of this area's history, it is also a part of its present. In fact, from a public health perspective, malaria is not really exotic at all. Surprisingly, hundreds of cases of imported malaria are reported in Canada each year, many of these within the GTA. However strange this may seem in this region, the phenomenon is quite straightforward. Any time an individual travels to or emigrates from a malaria-endemic region, they risk acquiring an infection and importing it back to Canadian soil. Although overwhelmingly an immigrant health problem in terms of the demographics of infection cases, we begin to see that this disease is as relevant to any Canadian-born person in the GTA as it is for an immigrant.

New, emerging, and re-emerging infectious diseases are but one of the predicted impacts of climate change. In the Toronto region, diseases such as West Nile Virus and Lyme disease have already made their presence known, and are ‘new’ to the area in that their range has expanded to include new ground. Malaria, because of its documented history in southern Ontario, has the potential to represent a ‘re-emerging’ disease, should local transmission occur. As a vector-borne disease, malaria requires a ‘middle man’, that is, a mosquito vector, in order to be transmitted from person to person. Therefore, environmental requirements must be met for both the parasite and the vector simultaneously to achieve successful transmission. In fact, the region of southern Ontario supports populations of mosquitoes capable of transmitting the parasite, and the regional climate is suitable for local transmission, just as it was over 100 years ago. Fortunately, local transmission does not exist at this time, and any cases we do see have been imported. However, as we look to the future, projected changes in climatic conditions may have unforeseen impacts on this local transmission potential. That said, environmental suitability does not immediately result in an outbreak of malaria. We know this because the disease was eradicated in the early 1900s and has not returned since as a locally transmitted infection. Other factors such as the strength and competency of Canada’s health care system, surveillance capabilities, and global malaria trends and drug resistance also move alongside one another to shape health outcomes here within this urban setting of the GTA.

And what a setting it is! A combination of high population densities, a significant influx of travellers and immigrants, and the exceedingly multicultural nature of the region’s population is already providing ideal conditions for a very high per capita rate of imported malaria. This brings us to possibly the most important factor, that is, the population itself. Broadly speaking, the vast majority of Canadians are highly susceptible to a malaria infection due to a lack of

immunity; however, the risk of acquiring an infection is not distributed equally among all individuals. The likelihood of travelling to malaria-endemic regions, seeking pre-travel advice, and obtaining and adhering to an anti-malarial drug regime differs from person to person. As we will discover, certain subpopulations begin to emerge as being particularly vulnerable. But how is vulnerability defined here and throughout this paper?

Vulnerability to a malaria infection encompasses a number of factors. In the most immediate sense, those include the aforementioned variables. Immunity, country of origin (as first or second generation immigrants), travel habits, and access to the health system all come together to influence the likelihood of infection as well as the health outcome itself (e.g. severity of infection). However, one must delve deeper to uncover the factors that influence those variables. In other words, how do an individual's social and economic conditions dictate their ability to make certain choices in the interest of their own health? The social determinants of health (SDOH) model is characterized by these considerations and ultimately provides a tool to uncover the underlying determinants which influence health outcomes within our societal context, including those influencing the incidence of infectious diseases. However, as it stands today, the discussion on imported malaria sits very snugly within a medicalized context, whereby those broader determinants are, for the most part, passed over. This paper will explore how that medicalized context influences perceptions on imported malaria, as well as the resulting policy recommendations.

Malaria will also be explored within climate change discourse in terms of the possible re-emergence of this disease in the form of sporadic local outbreaks. Analyzing this portrayal of malaria (imported or re-emergent) may provide some insight into how this disease may represent a health disparity among multi-generation immigrant groups in the GTA in the future. It may

also be telling of the manner in which infectious diseases in general are perceived by society and by the medical and public health communities. Ultimately, this paper aims to provide a case for why infectious diseases, including those which are climate-sensitive, should be examined through a SDOH lens in order to fully grasp the extent of their reach within our society. This does not mean simply identifying vulnerable groups and their needs based on socioeconomic indicators; it is also imperative that proposed actions work towards diminishing that state of vulnerability from the start.

This paper will implement a systems approach to define, analyze, and draw conclusions from the issue of imported malaria within the GTA, as well as the potential for malaria to re-emerge within a future climate change scenario. Berrang-Ford et al. (2009) describe a number of common factors to consider when studying a topic that involves both health and environment, including multiple disciplinary perspectives (e.g. human and biophysical environments), qualitative factors which affect transmission (e.g. level of economic development, public health measures), and processes acting within and across multiple spatial and temporal scales.

In the interest of length, this paper will concentrate on a certain number of disciplinary approaches which will be discussed below. These multiple disciplinary perspectives, by default, incorporate the aforementioned qualitative factors into this analysis, and address the issue across spatial and temporal scales.

Chapter 2 (*Malaria in Canada: Global and Regional Perspectives*) will include ecological, biological, and environmental considerations of malaria-specific pathogen and vector dynamics, thus providing an introduction to malaria as an infectious disease. Also included will be the direct health effects of malaria, from a medical perspective. Global malaria trends and the manner by which they fall within climate change considerations are also highly central to this

analysis. Finally, the issue of imported malaria within the Canadian context, and the degree to which Canada's public health infrastructure is adequate in meeting the population's current needs, address certain qualitative factors which expand on the breadth of this discussion.

Chapter 3 (*Climate Suitability for Malaria Transmission: Projections for Southern Ontario*) will cross temporal scales by examining future climate projections for the region of southern Ontario, and how these may coincide with temperature and precipitation requirements for malaria transmission.

Chapter 4 (*Urban Health and Population Demographics in the GTA: Uncovering Vulnerability among Immigrant Groups*) will look at health and income demographics as well as population and immigration trends in an attempt to understand which groups may face disproportionate risk of imported malaria and why. Here we may begin to speculate how these groups may also fare in the future, situated within a climate change scenario.

Chapter 5 (*Malaria within Climate Change, Infectious Disease, and Public Health Discourse*) deals with the way in which malaria and infectious diseases in general are perceived within medical and public health dialogues. We will explore how these dialogues are reflected within federal and provincial reports over the past decade, and by means of interviews with prominent municipal experts in the fields of infectious disease research, infectious disease policy, and climate change policy. Here, Canada's broader political and economic context will be brought to the forefront in terms of the potential barriers it presents to positive social change.

Chapter 6 (*Historical Malaria in Ontario*) looks to the past, and uses environmental history as a tool to draw lessons from how endemic malaria in southern Ontario was perceived during the 18th and 19th centuries. Here, the focus is on who exactly were the vulnerable groups

at that time, and ideally, what we might be able to learn in terms of addressing the present-day issue.

Although an in-depth examination of the SDOH model will occur specifically in Chapter 4, the application of the SDOH, as a theoretical framework, runs throughout all chapters, tying them together. This will not only help to understand the issue of malaria (imported and re-emergent) by examining its many facets, but will also make attempts to demonstrate how vulnerable groups are negatively affected by policy and perceptions about malaria, infectious diseases, and even about health in general. Ultimately, the extent to which these dialogues hold a place for the social determinants of health will be called into question.

Chapter 2

Malaria in Canada: Global and Regional Perspectives

2.1 Malaria: A General Introduction

Plasmodium biology and ecology

Malaria is caused by the *Plasmodium* parasite, of which there are four species that infect humans. Two of those four species, *Plasmodium vivax* and *Plasmodium falciparum*, are the most common globally and represent the vast majority of imported cases of malaria in Canada. Therefore, this study will focus on *P. vivax* and *P. falciparum* as they are most relevant within the Canadian context.

The life cycle of *Plasmodium* requires two hosts: *Anopheles* mosquitos act as the vector and definitive host (in which the sexual phase of the life cycle occurs, and where the parasite matures), and humans as the intermediate host (in which the asexual phase of the life cycle occurs). Within the mosquito host the *Plasmodium* requires a certain number of days within a certain temperature range (the ‘extrinsic incubation period’) in order to fully develop. These exact environmental requirements specifically in reference to *P. vivax* and *P. falciparum* will be discussed in detail in the chapter that follows.

The intensity of malaria transmission is highly linked to, and dependent upon, the longevity of its vector host. When a female mosquito obtains a blood meal from a human infected with malaria, they will pick up male and females gametocytes. These then reproduce sexually within the mosquito to produce sporozoites. Should that mosquito survive long enough for the sporozoites to complete their development cycle (also referred to as the sporogenic

cycle), the mosquito itself becomes infective, and is now capable of transmitting malaria to another human host.

Anopheles quadrimaculatus is considered the most competent vector for autochthonous (locally transmitted) cases of malaria in the eastern United States, and its distribution also includes southern Ontario and southern Quebec (Darsie & Ward, 1981; Levine et al., 2004; Zucker, 1996). As such, *An. quadrimaculatus* also represents the most competent vector for any local outbreaks of malaria in Ontario or Quebec, should they occur (Berrang-Ford et al., 2009). Competence in this context simply refers to the vector's capacity to transmit a particular pathogen; in other words, not all species of *Anopheles* are capable of transmitting malaria. Understanding the breeding preferences and overall behaviour of *An. quadrimaculatus* is also relevant here.

Depending on the developmental stage (there being four), *An. quadrimaculatus* can be found in a wide variety of habitats. Egg, larva, and pupa are found in freshwater aquatic environments such as ponds and marshes. However, any type of standing water will often suffice, e.g. puddles inside a tire or on a field. Adult mosquitoes tend not to stray too far from breeding sites. However, should there be a lack of hosts, they are capable of flying up to 4km. Finally, mosquitoes tend to be most active at dawn and dusk, when adults feed. When an adult female bites a human, *Plasmodium* sporozoites are injected into that person's bloodstream via the mosquito's saliva, and continue their life cycle within the human. In addition to humans, *An. quadrimaculatus* also feed on cows, horses, dogs, cats, and birds, among other animals. Due to their versatility in terms of breeding sites and potential hosts, urban and suburban as well as rural environments are highly capable of supporting *Anopheles* populations.

As with *Plasmodium*, *Anopheles* too have environmental requirements for development. The specific requirements for *An. quadrimaculatus* will be discussed in detail in Chapter 3, Climate Suitability for Malaria Transmission: Projections for Southern Ontario. However, in brief, since insects are cold-blooded, all aspects of their life are directly determined by temperature and humidity. In general, the warmer the water, the faster immature stages will develop. However, temperatures beyond a certain upper limit are damaging. Temperature also determines the length of the adult mating season (anywhere from early spring to late fall) as well as their feeding behaviour. Higher temperatures facilitate digestion of blood meals resulting in higher biting rates, which in turn have the potential to increase transmission rates of malaria. Finally, mosquitoes require a certain degree of humidity in order to survive. Therefore, a certain amount of rainfall is necessary to support *Anopheline* populations. Humidity and temperature along with host abundance and predation influence the longevity of the mosquito, which ultimately impacts the potential malaria risk as well as the severity of transmission.

Health effects of malaria

Malaria is considered the most deadly vector-borne disease in the world, killing over 1.2 million people every year worldwide (WHO, 2014). Its health effects are greatest among populations that lack immunity, such as those not normally exposed to malaria, or those who are only exposed for a certain period every year. Typically, after being bitten by an infective mosquito, a period of 7-30 days passes before any signs or symptoms appear, although this period tends to be shorter for *P. falciparum* than for *P. vivax* (CDC, 2010). These symptoms are the result of the presence of blood stage parasites, and include fever, chills, headache, and vomiting. If not treated within 24 hours of showing symptoms, a *P. falciparum* infection can

quickly progress to a severe infection which often results in death. Again, this is of particular concern among non-immune patients, and is treated as a medical emergency regardless of the severity of the infection. The latest estimates are of approximately 627,000 deaths from malaria in 2012 (WHO, 2013a). For those who survive, severe malarial infections can result in long-term health effects such as severe brain damage and cognitive impairment (more common among children), renal failure, or coma. Although *P. falciparum* tends to be responsible for severe infections, once treated correctly, the illness does not return. *P. vivax*, on the other hand, can relapse months or, less commonly, years after the initial exposure (NIMR, 2009). Finally, the point at which the patient him or herself becomes infective (when gametocytes are present within the bloodstream) differs between the two species. With *P. vivax*, gametocytes form within a few days after infection. With *P. falciparum*, gametocytes take 10-14 days to form. However, most patients would have received treatment by this time and would thus have become unable to transmit the malarial infection.

P. vivax has a wide global distribution as its range extends into temperate zones, whereas *P. falciparum* is limited to the tropics and subtropics. As of 2013, 97 countries and territories were susceptible to malaria, with the vast majority of cases occurring in sub-Saharan Africa (WHO, 2013a). As previously mentioned, those populations which lack immunity to malaria are the most vulnerable. On an individual level, this not only includes people from non-endemic areas, but also immigrants now living in non-endemic areas whose immunity may have waned or disappeared altogether. Also considered susceptible are those whose immune system is compromised in some way, such as pregnant women, young children, and individuals with HIV/AIDS. Not only do these groups face a higher risk of contracting malaria, but they also face a greater risk of experiencing a more serious degree of illness. For example, the *Canada*

Communicable Disease Report (CCDR) published by the Public Health Agency of Canada (2008) warns international travellers who have underlying medical conditions of the potential impact of a malarial infection on that condition. In addition, the interactions between anti-malarial prophylaxis and other medications are difficult to predict and can cause further complications.

For those with HIV/AIDS, malaria is of particular concern because the reciprocal relationship between the two diseases is highly complex and not fully understood. Increased stimulation of HIV viral replication among patients experiencing a malarial episode (*P. falciparum*) has been observed, as well as an increased susceptibility to malaria among patients who are HIV-positive (Abu-Raddad et al., 2006). This corresponding increase in malaria risk and parasite density with a weakening immune system is somewhat intuitive, although how this interaction might play out within the Canadian context is difficult to say.

In fact, interactions between the immune system and the malaria parasite are not even fully understood, let alone interactions between HIV and malaria. Barclay et al. (in press) discovered that *P. chabaudi* (a species of malaria in mice) became more virulent and aggressive in immunocompromised mice, whereas one might expect the opposite result. It was posited that since the immune system was not inhibiting replication of the parasite, it was able to multiply to such high densities that competition for red blood cells became very fierce. At this point, not only would selection favour those that matured quickly, but a bigger gene pool would have increased the likelihood of more virulent mutants. Since these biological patterns were observed only in mice, it cannot be assumed that they would occur similarly in humans; however, these types of studies are nevertheless informative of the potential threat such a disease may have among immunocompromised individuals.

2.2 Global Discourses on Malaria

Current Distribution of Malaria

Malaria was common in much of Europe until the second half of the 20th century after which it was eradicated; a few exceptions include Azerbaijan, Georgia, Greece, Tajikistan and Turkey, which all reported cases in 2012 (WHO, 2013b). Therefore, many European countries already have the climatic conditions to support malaria transmission. Along with a climate favourable for both *Plasmodium* development and vector reproduction and survival, the necessary conditions to support transmission of this disease also include a competent *Anopheles* vector presence along with adequate breeding sites, and an influx of infected individuals arriving or returning from malaria-endemic regions.

For this reason, even in several of the wealthier, more developed countries in Europe which are now malaria-free, there still may be varying degrees of susceptibility to malaria should they meet all the above criteria. For example, one region in northeastern Spain was deemed to have high malaria receptivity, despite the fact that Spain, on the whole, has low vulnerability to infectious disease outbreaks as characterized by the strength and efficiency of its health infrastructure (Bueno-Marí & Jiménez-Peydró, 2013). In this case, the health infrastructure was the main limiting factor. As long as a nation's system is characterized by prompt disease identification and treatment, it can act as a security net to catch the inevitable imported cases of malaria.

Yet, every once in a while, an autochthonous case of malaria is diagnosed, and this has significant implications. Autochthonous cases of malaria are defined by individuals who contract the disease from a local mosquito without having travelled to a malaria-endemic country. That mosquito would initially have acquired the parasite from biting an infected individual in the area

who most likely contracted the disease abroad. Autochthonous cases of malaria have been recorded in Greece in 1994-1995 (Kampen et al., 2002), Italy in 1997 (Baldari et al., 1998), France in 2006 (Doudier et al., 2007), and Spain in 2010 (Santa-Olalla Peralta et al., 2010). Although these few isolated incidents may seem insignificant, for populations which lack immunity toward malaria, sporadic autochthonous outbreaks such as these can have serious population health implications such as the increased likelihood of severe illness, or even death.

Holy et al. (2011) conducted a study in Germany to evaluate whether certain areas were at risk of autochthonous transmission under current climate conditions in order to initiate prevention where necessary. Like many other countries in Europe, Germany has a history of malaria endemicity. Specific ‘hotspots’ were identified, areas which were densely populated, had suitable climate conditions for malaria transmission, and had a high proportion of immigrants and/or tourists. Frankfurt airport was of particular concern. Germany has already experienced two autochthonous cases of *P. falciparum* in 2007 in areas where the mean daily temperatures were between 21-27°C. A changing climate is expected to increase malaria transmission potential in these areas.

Finally, endemic malaria in the United States was eradicated around 1950. Since then, the vast majority of all malaria cases have been imported. However, since then there have been an increasing number of local outbreaks (Zucker, 1996). The most recent episodes occurred in densely populated urban or suburban areas and during periods of abnormally hot and humid weather. It is clear that warmer, wetter weather certainly played a role in the abundance of *Anopheline* vectors and/or facilitated *Plasmodium* development. Local outbreaks of imported malaria have been recorded widely in parts of the U.S., including California, Georgia, Florida, Louisiana, Maryland, New York and New Jersey (CDC, 1982; CDC, 1986; CDC, 1990; CDC,

1991; CDC, 1997; Layton et al., 1995). These incidents are noteworthy considering the similarity in socioeconomic status and overall adaptive capacity of the health system between the U.S. and Canada. However, unlike the U.S., there has only been one case of ‘probably’ locally acquired malaria ever recorded in Canada since its eradication. This occurred in Toronto in 1996 when a woman contracted *P. vivax* despite not having travelled to any malaria-endemic region in the past nine years (Baqi et al., 1998). Warm and humid conditions defined the summer that year, most likely facilitating transmission.

Broader-scale, global studies on malaria risk are relevant for Canada’s own health security. There is evidence to support the hypothesis that changing rates of malaria incidence in endemic countries influence the incidence of imported cases in Canada (MacLean et al., 2004). Certain authors have worked on mapping current populations at risk of malaria on a global scale (Guerra et al., 2008; Guerra et al., 2010; Kuhn et al., 2002). Guerra et al. (2008) mapped *P. falciparum* and identified 2.37 billion people at any risk of transmission, the most vulnerable region being Africa. Guerra et al. (2010) mapped *P. vivax* and identified 2.85 billion people at risk, the vast majority of which were in central and Southeast Asia. In addition to informing malaria risk here at home with regard to imported cases, the models produced in these studies can be also used to determine risk under future climate scenarios.

Malaria and Climate Change

Predictive modelling is essential as a means of estimating future malaria risk in the context of climate change, where temperature and precipitation are the two main climatic factors influencing transmission potential (see the discussion on *Plasmodium* biology and ecology, above). Socioeconomic factors such as the adaptive capacity of a nation and population growth

have more recently been recognized and included in models (Lafferty, 2009; van Lieshout et al., 2004). Through a variety of modelling techniques, many studies have estimated changes in transmission potential, populations at risk, along with the areas which are expected to bear the greatest disease burden. One conclusion is that temperate zones such as North America and Europe will see the greatest changes in malaria risk due to their highly sensitive climate (Martens et al., 1995; Martens et al., 1999). It is said that even a small increase in climate suitability may result in a disproportionate increase in transmission potential, an increase which, in a population that lacks immunity, could have disastrous effects (Haines et al., 2006; Martens et al., 1995; Martens et al., 1999). In other words, the effects of climate change on transmission potential are likely nonlinear.

Another common output from such predictive modelling is that developing nations characterized by a low adaptive capacity, such as Asia and Africa, can expect to bear the greatest disease burden, as measured by disability-adjusted life years (DALYs) (Martens et al., 1995; van Lieshout et al., 2004). This would be due to a geographical expansion of susceptibility into these areas. DALYs are a health measure defined by the number of years of healthy life lost to disease, in this case, malaria. Van Lieshout et al. (2004) further estimated that the poorest, least socioeconomically stable regions in the world, those which already experience high rates of malaria transmission, will not be as affected, and that risk may in fact diminish in certain areas. Not only may the geographical distribution of malaria be affected, but also the seasonality of transmission (Haines et al., 2006; Martens et al., 1999). Holy et al. (2011) mapped areas at risk of malaria transmission in Germany based on predicted future temperatures, and saw prolonged transmission seasons as a result, up to six months in length under one climate scenario.

More modest changes in risk represent an alternate prediction, such as risk distributions not much different than those we see today (Rogers & Randolph, 2000), or scenarios which actually see a net decrease in disease transmission (Lafferty, 2009). One regional study conducted in France suggested that an increase in malaria risk would only occur under a specific and unlikely combination of unfavourable conditions, and that certain results of climate change such as flood events would in fact limit risk (Linard et al., 2009).

This is where an examination of the weight of each determining factor is useful. For example, Kuhn et al. (2002) discovered that climate was a much better predictor of competent malarial vector species in Europe than was land cover. However, although temperature and precipitation are considered significant determinants of disease distribution, other non-climatic factors are potentially more relevant. For example, population growth was found to be a greater predictive driver of future populations at risk of malaria than climatic factors (van Lieshout et al., 2004); land use changes may prevent transmission despite ideal climate conditions (Lafferty, 2009); effective control measures and economic stability may very well limit malaria risk in developed regions, such as those with ‘Anophelism without malaria’ (Martens et al., 1995); and the vulnerability of a nation towards malaria tends to be based on overall socioeconomic status as well as the malaria control status (van Lieshout et al., 2004). Therefore, models that include only climatic variables could be considered simplistic; similarly, models that define vector abundance alone may only generate rough maps of malaria risk.

However, we cannot always make the assumption that high overall socioeconomic status or economic stability ensures low malaria risk. For example, Zucker (1996) describes the clinical nature of the issue of local outbreaks in non-malarial areas in the U.S. where there is a real potential for delays in detection, especially if the infected individual has not travelled abroad.

Misdiagnoses or lack of disease reporting is a result of general inexperience in the field of tropical infectious diseases within typical clinics or labs (Zucker, 1996). Increasing drug resistance was also noted as a potentially exacerbating factor. Likewise, even countries that are highly developed and economically stable such as the U.S. may still have a strong presence of vulnerable groups, therefore, assessing risk may not necessarily be straightforward.

On the whole, vulnerability on an individual or group level was only superficially accounted for in the studies examined up to this point. ‘Human susceptibility’ (i.e. the probability of successful transmission by an infective mosquito to a human) is recognized as a main component in the calculation of malaria transmission potential (Martens et al., 1995; van Lieshout et al., 2004). This value is said to depend both on immune processes and genetics, and would theoretically vary from person to person. However, since this parameter is assumed not to be climate sensitive, it is given a constant value within any calculations. Therefore, individual human susceptibility is at most recognized and described within the literature, but not truly accounted for among the studies examined here. Likewise, recognition of the vulnerability of certain groups within a population is essentially nonexistent.

2.3 Malaria in Canada

Canada’s Place on the Global Malaria Stage

The lack of references to Canada in the previous discussion may allow for some idea of its relevancy from a global perspective. Neither Canada nor the United States were identified as current risk areas for either *P. falciparum* or *P. vivax* in several global malaria risk models (Guerra et al., 2008; Guerra et al., 2010). In terms of future risk, Martens et al. (1999, p. S96) describe Canada as being the ‘climate limits for parasite’. This classification is curious

considering Canada's climate did historically support malaria transmission and theoretically is still capable of doing so under current climate conditions. Although Canada is generally classified as a non-endemic area, southern Ontario specifically may be defined as an area with *Anophelism* without malaria, in that its climate supports *Anopheles* mosquitoes.

An. quadrimaculatus is recognized as being a competent vector in southern Ontario and Quebec, although Canada is in fact only on the periphery of its distribution (Darsie & Ward, 1981; Zucker, 1996; Levine et al., 2004). In these marginal zones, model predictions may be less reliable. This is because adaptive capacity and development status play such a strong role in limiting malaria risk, and global models are simply not designed to estimate risk in these marginal, non-endemic regions (Berrang-Ford et al., 2009). Although Canada only represents a marginal region, it is crucial to point out that the vast majority of the Canadian population live along the border with the U.S. This means that even a small increase in transmission potential or risk in the southern portion of Canada could have significant health outcomes. Although Martens et al. (1999) allude to possible future risk in areas that historically supported epidemic or endemic malaria transmission (Europe, Australia, U.S.), Canada is never mentioned although it too has a history of endemicity. Therefore, in order to fully grasp the multitude of influential factors within the specific context of southern Canada, one must look to studies that have taken a regional perspective.

Studies on Malaria in Canada

There are very few studies that examine malaria risk in Canada within the context of climate change, possibly because it does not represent a current health concern but rather only the threat of one. We may recall the singular incident in Canada's recent history of the case of

locally-transmitted malaria. Despite being an isolated case, the public health implications cannot be ignored since it was demonstrated that sporadic outbreaks of autochthonous malaria here in Canada are indeed possible. Yet, there is a considerable gap in academic literature on this particular issue. To date, no study has used predictive modelling to quantitatively estimate future malaria risk in Canada. Nonetheless, Berrang-Ford et al. (2009) determine that sporadic autochthonous outbreaks in southern Canada are an increasingly real possibility. Using qualitative methods, climate projections for southern Ontario were found to describe a lengthened transmission season, increased vector abundance, and a rise in overall transmission suitability due to changing temperature and precipitation patterns. These climate projections will be discussed in detail in Chapter 3.

Changing trends in immigration and travel destinations, as well as the potential for increased immigration from areas suffering from the impacts of climate change (i.e. environmental refugees) are also important when it comes to estimating changes in malaria risk (Berrang-Ford et al., 2009). For example, there has been a steady increase in immigrants and refugees to Canada from the Indian subcontinent over the years, as well as increased rates of travel to and from malaria-endemic countries (MacLean et al., 2004). These factors, combined with the fact that the range of the most competent vector for *P. falciparum* and *P. vivax* in this area (*An. quadrimaculatus*) includes several large urban centres (including Toronto), may present a real challenge.

Indeed, incidence and parasitemia (i.e. percentage of parasitized red blood cells) is expected to be greatest in urban centres such as the Greater Toronto Area (GTA) (Berrang-Ford et al., 2009). Much like Frankfurt Airport (Holy et al., 2011), Pearson International Airport is

situated within a relatively dense regional population that sees a significant influx of immigrants, tourists, and travellers, many arriving from malaria-endemic regions.

Finally, warmer, longer summers may not only boost transmission suitability based on biological parameters, but are also expected to influence the behaviour of the public, whereby more time spent outdoors would increase the rate of interaction between people and mosquitoes, increasing exposure to infection (Berrang-Ford et al., 2009; Charron, 2002).

To understand the issue of malaria in Canada as it sits today, an examination of current national statistics on malaria, as well as those in Ontario specifically, is highly relevant. Generally speaking, the vast majority of all cases of malaria reported in Canada are imported; however, the number of these cases in major urban centres has been steadily increasing (Lee et al., 2013). Within the last decade, this number has averaged around 400 cases per year (PHAC, 2013a). In 2010 and 2011, rates spiked to over 500 cases per year. More alarmingly, the Public Health Agency of Canada (2004) states that these numbers may only represent 30-50% of actual cases. Given these data, we may speculate that underreporting is a clear issue in terms of gauging the real current impact of imported malaria in Canada.

Severe cases of malaria are much less common. For example, the number of severe cases recorded from 2001-2008 ranged from 8 to 20 cases annually (PHAC, 2013b). However, the prevalence of severe cases as seen is an increasing concern in Canada (Kain et al., 2001). Even within modern intensive care unit settings, severe malarial infections caused by *P. falciparum* can have a case fatality rate of 20% or more (Campbell, 1991). Considering the urgency of severe malarial infections, even one case is highly worrisome. Furthermore, malaria as a specific cause of death is not reported by any government agency therefore only an estimate can be obtained as through various academic studies. Nine deaths from severe malaria among Canadian

travellers were reported between 1997 and 2001 (Humar et al., 1997; Kain et al., 2001).

Although this figure may seem low, a trend of an increasing proportion of *P. falciparum* in North America is a definite concern, especially considering the ability of a *P. falciparum* infection to proceed quickly to a severe infection (Lee et al., 2013; MacLean et al., 2004; Zucker, 1996).

A significant portion of all national cases are reported in Ontario; for example, 230 out of 517 cases in 2011, representing incidence rates that are higher than the national average (PHO, 2014). Furthermore, many of these cases appear to be concentrated within the Toronto and Peel regions, for example, accounting for 68% of all cases in that same year. The *Reportable Disease Trends of Ontario* report (describing ten year trends with a focus on 2011) published by Public Health Ontario also states that *P. falciparum* was the most commonly reported species of malaria in 2011, accounting for almost half of all cases (*P. vivax* was 39%, *P. ovale*, 4%, and the remaining 11% unspecified). Africa (including 23 countries mostly in West Africa), India and Pakistan accounted for the majority of travel destinations as reported for the 2011 cases. Males represented the majority of all cases, 70% in 2011. Also, the age groups 20-29, 30-39, and 40-49 saw the highest incidence of malaria in 2011.

Malaria has a higher incidence than any other reportable vector-borne disease in Ontario (PHO, 2014); however, in terms of vector-disease burden, West Nile Virus (WNV) ranks first, followed by dengue, and then malaria which is ranked number 41 out of 51 for both burden and average annual deaths (Kwong et al., 2010). To provide a means of comparison, one health measure used to calculate the total disease burden of a particular pathogen is ‘years of life lost due to premature mortality’, or YLLs. Hepatitis C, the most burdensome reportable infectious disease as of 2010, accounts for 7,729 YLLs, whereas malaria accounts for only 6 YLLs (Kwong et al., 2010). Based on these figures alone malaria does not appear to represent a significant

health concern as it stands today, at least not compared with other infectious diseases. However, the issue of underreporting must again be taken into consideration. If we were to double or triple the rates of reported malaria as they most likely are in reality, the disease may begin to receive more attention.

Challenges with Malaria Management in Canada

The management of malaria involves multiple processes at various levels of a health system. As such, there are many places where something could go wrong. However, there is a substantial difference between the occasional mishap, and problems within the system itself. Seeking pre-travel advice along with the appropriate adherence to chemoprophylaxis is very important not only for tourists travelling to malaria-endemic areas, but also for individuals who are returning to their country of birth. It is widely understood that protective immunity diminishes after even a few months of non-exposure. Returning immigrants are less likely than other travellers to take prophylaxis and therefore may face a higher risk of acquiring malaria because they may still believe they are immune, or generally underestimate their risk of infection (Lee et al., 2013). Generally, however, there is evidence that a significant proportion of travellers do not seek pre-travel advice, and that only a fraction of those who do seek advice intend to use prophylaxis or use personal protection measures such as bed nets or repellent (Kain et al., 1998; MacLean & Ward, 1999).

The failure to use prophylaxis is thought to extend beyond a general inadequacy in the knowledge and practice of malaria prevention among members of the public, to the system itself: inappropriate pre-travel advice and general lack of knowledge of health care providers has been well documented here in the GTA (Kain et al., 2001; MacLean & Ward, 1999). To complicate

matters further in Ontario, the cost of travel clinic visits is no longer covered by the province; this combined with increasing costs of antimalarial drugs result in people being less likely to adhere to appropriate measures (MacLean & Ward, 1999).

Upon their return from abroad, delays in recognition represent another substantial concern (Kain et al., 1998; Zucker, 1996). In fact, Kain et al. (1998) identified significant issues at all stages of malaria case management within the GTA: recognition of malaria, misdiagnosis by the physician (in 61% of cases), lab diagnosis, and initiation of treatment. For example, among patients who visited centres without tropical medicine specialists, nearly 50% received inappropriate drug therapy. Since the vast majority of travellers do not begin to feel the symptoms of a malaria infection until they return home, it is necessary for the system we have in place here in Canada to be competent, and for physicians and healthcare practitioners to have experience in recognizing tropical infections such as malaria. However, the clear systemic problems that lie within the GTA's ability to identify and manage imported cases of malaria is worrisome, especially since this area represents one of the largest hubs of travel and immigration in Canada.

In one study, immigration numbers and changing travel destinations were not found to be directly associated with fluctuations in provincial or national malaria rates; however, it was posited that the federal surveillance system itself lacks validity and may be responsible for these unexpected results (MacLean et al., 2004). The federal notifiable disease database, comprising a compilation of selected information from provincial databases, does not collect data on 'country of acquisition' or on the species of malaria. However, although Canada may lack a formal, nation-wide surveillance system for malaria (such as exists for WNV), Ontario has had an integrated Public Health Information System (iPHIS) since 2005 which reports on disease

surveillance. Also, the GTA established an active surveillance system for malaria in 1994. By law, all diagnostic labs in Ontario are required to report cases of malaria to the provincial lab for confirmation. As such, the system can only be as good as the information being entered. Unfortunately, as Kain et al. (1998) discovered, there are significant errors occurring not only in initial patient diagnosis, but lab diagnosis as well. Therefore, the reliability of malaria surveillance in Ontario and the GTA is dubious.

2.4 Challenges of Modelling Malaria and Recommendations

There are many challenges faced when implementing predictive modelling or when estimating current pathogen and vector distributions. Above all, entomological (insect) parameters are the most difficult to measure because the underlying biological processes are in a constant state of flux. Furthermore, there is a general lack of reliable historical data on both vector and pathogen distributions (Martens et al., 1999; van Lieshout et al., 2004). Martens et al. (1999) point out that in previously endemic areas such as in Europe or North America, gathering this information may no longer have been prioritized after the point of eradication, and is therefore rarely up to date. As of today, the actual distribution and abundance of *Anopheles* mosquitos in Ontario, let alone Canada, is unknown. Despite these setbacks, the utility of such models in identifying areas of potential risk under a variety of future climatic scenarios is still beneficial. Due to the fact that no quantitative predictive models have yet been created to estimate future disease risk in Canada, global models at least provide some idea of the degree of threat we may face in terms of imported malaria. Moreover, increased global migration resulting from the impact of future climate change is also relevant for Canadians as changes in transmission potential abroad become more relevant here at home.

Recommendations provided by regional and global studies on current and predicted global malaria risk revolve around: (1) improvements in education of both travellers and healthcare providers (Berrang-Ford et al., 1999; Haines et al., 2006; Kain et al., 1998; Kain et al., 2001; MacLean & Ward, 1999); (2) targeted public health interventions in high risk communities (Berrang-Ford et al., 1999; Eckhardt et al., 2012; Lee et al., 2013); (3) improvements in recognition, diagnosis, and treatment of malaria cases, particularly outside of tropical disease reference centres (Kain et al., 1998; Kain et al., 2001); (4) improvements in pathogen and vector surveillance processes (Berrang-Ford et al., 1999; Bueno-Marí & Jiménez-Peydró, 2013; Haines et al., 2006; Holy et al., 2011; MacLean et al., 2004; Martens et al., 1995; Santa-Olalla Peralta et al., 2010) and (5) research that focuses on regional malaria risk modelling which integrates both environmental and socioeconomic parameters (Berrang-Ford et al., 1999).

Although all of these measures are indeed crucial for the management of imported malaria in Canada or for working towards an improved system of surveillance for future cases, it is interesting to note that the majority are, in essence, reactive rather than preventative. Many of the recommendations cited here are situated within a medical dialogue, and thus contribute to the medicalization of this issue. Zucker (1996) was the only author among those discussed here who proposed preventative measures such as improved housing and access to health care in the U.S. There is a lack of discussion on the importance of tackling the root causes of the unequal distribution of malaria incidence generally and within Canada. Even among those studies whose results provided evidence of inequality in malarial health outcomes (which will be explored in greater detail in Chapter 4), we saw a similar picture (Eckhardt et al., 2012; Lee et al., 2013). As with the global prediction of disease burden falling on the shoulders of the poorest, least capable nations, a similar outcome may very well have implications on a population level within Canada.

Should malaria incidence in Canada worsen in the future, whether this is climatically determined or otherwise, there is a real potential for more severe health outcomes to fall along those same lines of inequality, most likely deepening them further.

2.5 Conclusion

The issue of malaria in Canada within the global context may, to some degree, be overlooked, currently and within future estimates of malaria risk. Certainly, one cannot compare the degree to which developing nations already suffer or may suffer from malaria, to the Canadian context. However, such comparisons are neither useful nor explanatory. The risk of sporadic autochthonous outbreaks in southern Ontario presents a potentially very real and dangerous scenario, particularly for a population that lacks immunity. Again, severe *P. falciparum* infections are a cause for emergency, therefore, any increase in the number of cases of malaria pose a significant public health concern. Increasing rates of immigration from and travel to malaria-endemic countries resulting in rising rates of imported malaria of which an increasing proportion are *P. falciparum* cases is certainly worrisome when combined with issues surrounding underreporting, global drug resistance, the seeking of pre-travel advice, adherence to prophylaxis, identification, diagnosis and treatment, and lack of validity in the national surveillance system. These factors define the issue of malaria as it stands today in Canada.

Applying a scenario of climate change which increases malaria transmission potential leads one to believe that however capable the system is of managing imported malaria today in Canada, things are likely to become more complicated in the future. Furthermore, malaria is already the most prevalent vector-borne disease worldwide. A changing climate on a global scale will undoubtedly influence the status of malaria risk here at home through changing trends in the

composition of malaria species, drug resistance, as well as rates of importation. Finally, an examination of future malaria risk in Canada is not only useful in and of itself, but may also be representative of other vector-borne infectious disease threats influenced by climate change.

It is clear that the southern portion of Ontario is a useful focus. The GTA represents a potential ‘hotspot’ for malaria risk, as it is not only one of the largest hubs for immigration and travel, but it also currently lies within the competent vector and climatic transmission range. As previously mentioned, a closer examination of future climate projections and potential changes in transmission potential for this area will define the following chapter.

Finally, it is useful to step back and consider applying a broader perspective to the assessment of current imported malaria risk as it stands today in Canada. It is clear that, looking beyond the numerous issues pertaining to the logistics of malaria surveillance, management, treatment, etc., malaria itself sits within a highly medicalized context. The work being carried out by health care professionals on this subject has defined the issue as we understand it today. Therefore, the application of the social determinants of health (SDOH) model is perhaps very appropriate, whereby broader social and economic factors are considered in their impact on malaria as a health outcome within our societal context, factors that look beyond the most immediate medical consideration. Evidence, albeit limited, already exist that support the current distribution of malaria cases in large Canadian urban centres as defined by circumstances of social or economic disadvantage (Eckhardt et al., 2012; Lee et al., 2013). Again, these studies will be explored in Chapter 4. Yet, it is apparent that the issue of malaria within Canada sits only on the periphery of SDOH discourse. This paper aims to spur a reconsideration of how we view infectious disease, particularly malaria, in our society.

Chapter 3

Climate Suitability for Malaria Transmission: Projections for Southern Ontario

3.1 Introduction

Both *Plasmodium* spp. and its vector, *Anopheles* mosquitoes, require a number of favourable conditions in order for successful transmission of malaria to occur. As discussed in the previous chapter, an infected mosquito must survive long enough for the *Plasmodium* to complete its sporogonic cycle during which temperatures must fall within the appropriate windows for both the vector and the pathogen, and for a certain number of days. Only then can the mosquito itself become infective, acquire a blood meal, and finally transmit the malaria disease to a human. The dominant vector for malaria in eastern USA is considered to be *An. quadrimaculatus*, a mosquito whose range also includes large portions of southern Ontario and Quebec (Zucker, 1996). Therefore, *An. quadrimaculatus* also represent the most competent vector for malaria in these areas in Canada (Berrang-Ford et al., 2009). Finally, *P. vivax* and *P. falciparum* are the most common on a global scale and also represent the vast majority of imported cases in Canada.

Climate is a strong contributing factor when it comes to malaria incidence, although perhaps less so in wealthy developed nations. Nevertheless, outbreaks do occur in these regions where weather and climate appear to have played a prominent role. For example, Zucker (1996) documented local outbreaks of malaria in the 1990s in the U.S. which were all characterized by periods of abnormally hot and humid weather. As will be explored in more detail by examining the specific environmental requirements of this disease and its vector, the current climate

conditions for the area of interest, southern Ontario (the Greater Toronto Area in particular), are already suitable for malaria transmission. However, since almost all cases of malaria in Canada are currently imported, not locally transmitted, theoretical transmission does not necessarily equal actual disease risk.

Certain factors are capable of negating climate influences on disease risk. It is generally understood that factors such as the efficacy of vector control measures, surveillance, and the promptness of treatment of infected individuals are able to limit the impact of malaria as it is imported into the country. However, as we have discovered in the previous chapter, many problems lie within Canada's health and surveillance systems when it comes to malaria. Climate change may exacerbate this scenario through changes in temperature and precipitation patterns. This chapter will explore how future climate projections for southern Ontario may demonstrate changes in abundance of *An. quadrimaculatus* as well as in transmission potential for malaria in general. Since actual disease risk cannot be truly quantified through an exclusive examination of climatic variables, it must be understood that these variables are only discussed with reference to their impact upon theoretical transmission potential and climate suitability for malaria risk.

3.2 Environmental Requirements for Malaria Transmission

The temperature requirement for *P. vivax* to complete its sporogenic cycle within its mosquito host is approximately 30 consecutive days at 18°C, and for *P. falciparum*, 30 consecutive days at 20°C. With each rise in degree temperature, the rate of development increases proportionally, and the number of required consecutive days decreases as a result, e.g. 20 consecutive days at 20°C for *P. vivax*. Above 33°C, however, development will cease for either species. Similarly, the lower temperature thresholds for *P. vivax* and *P. falciparum* are

16°C and 18°C, respectively. These temperature conditions must then coincide with the environmental requirements of the vector host. Therefore, the requirements of the *Anopheles* become those of the parasite too.

As with *Plasmodium* spp., there is a similar relationship between temperature and rate of development for the vector. *An. quadrimaculatus* eggs develop into larvae, pupae, and then into adult mosquitoes in water, a development process that can take anywhere from 14 to 27 days with an average water temperature of 23°C: the warmer the water, the quicker the development (CDC, 2012). Below 12°C, larvae may drop to the bottom of their aquatic habitat until temperatures are warm enough for development to continue (Glyshaw & Wason, 2013).

The minimum level of monthly rainfall required for the availability of standing water and relative humidity for mosquitoes is 80mm for a minimum of four consecutive months and must coincide with the necessary temperature window (Berrang-Ford et al., 2009). Therefore, once the mosquito is an adult, both temperature and humidity influence its longevity or lifespan. Furthermore, female *An. quadrimaculatus* generally tend to live much longer than males (approximately 21 days vs. 7) (Glyshaw & Wason, 2013). As well as influencing the development rate of both mosquito and parasite within the mosquito and the longevity of the mosquito, temperature also affects their feeding behaviour. Warmer temperatures facilitate in the digestion of blood meals, and females will bite more as a result. Temperature also determines the length of the adult mating season which can range anywhere from April or May up to November in southern Canada. Finally, host abundance and predation are factors that limit mosquito abundance since birds and bats feed on adult mosquitoes, and aquatic birds, carnivorous insects, and fish feed on larvae and pupae.

3.3 Climate Projections for Southern Ontario

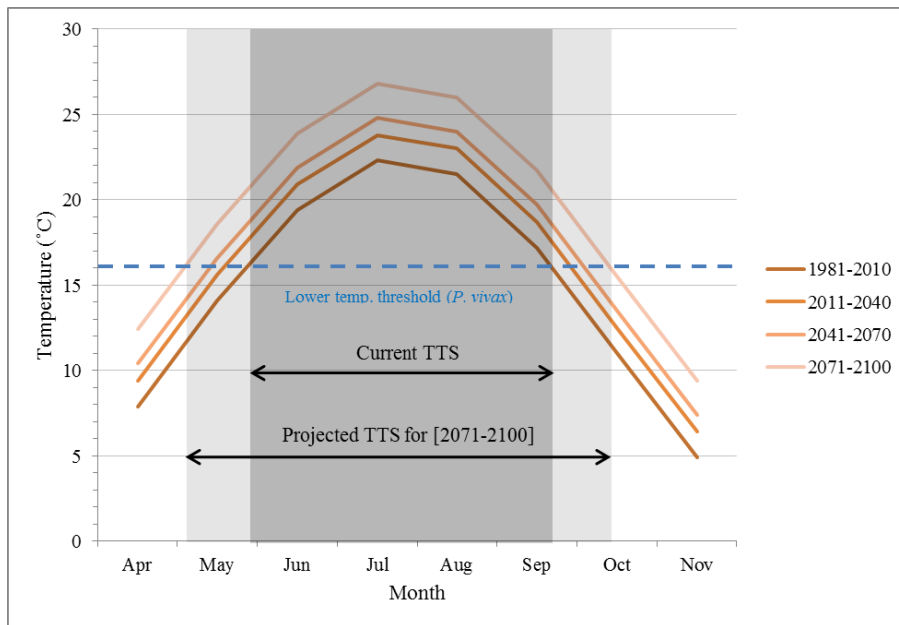
Temperature

The Ministry of Natural Resources (Colombo et al., 2007) used the Canadian Coupled Global Circulation Model (CCGCM) to produce expected average changes in temperature and precipitation for Ontario over 30 year periods, with a focus on the A2 IPCC scenario of atmospheric greenhouse gas levels. A2 represents a scenario of higher greenhouse gas levels, a greater reliance on fossil fuels, and a population of 15 billion by 2100, i.e. business as usual. By 2071, the GTA may expect to see an increase of 5-6°C of average summer temperatures, and a similar increase in the winter, although on the whole, warming is expected to be greater in the winter than in the summer (Colombo et al., 2007).

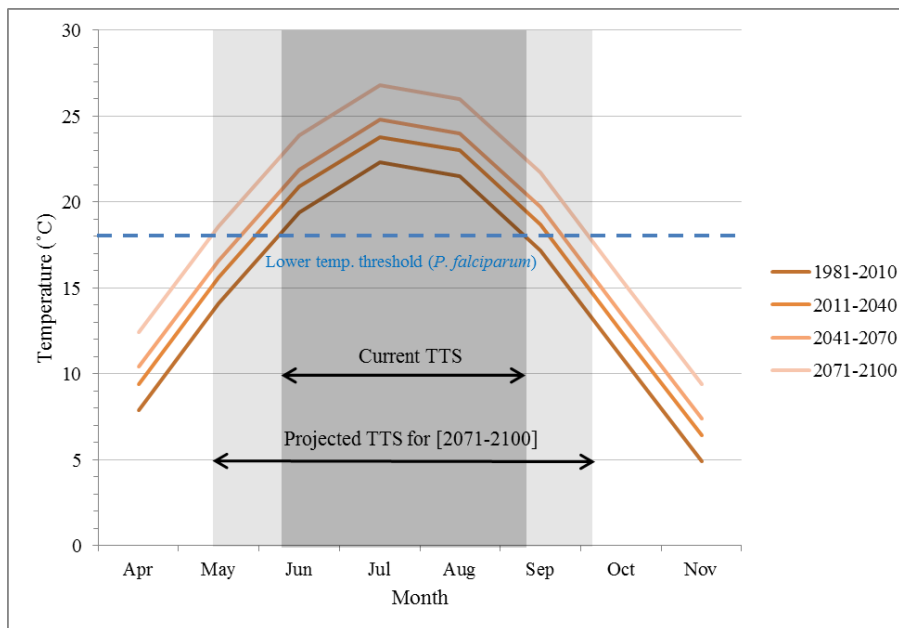
Based on the lower temperature thresholds for development of *P. vivax* and *P. falciparum* (16°C and 18°C, respectively), this projected increase in average summer temperatures may extend the potential transmission season for malaria. The current theoretical transmission season (TTS) for both species of malaria in Canada is limited, for the most part, to the months of June, July, August, and part of September; however, under the A2 scenario, this season may very well extend into May and October (Figure 1). Although this only demonstrates the TTS based on daily average temperature, it is still indicative of an increase in climate suitability for future malaria risk in southern Ontario. Warmer winters (October through March) may contribute to a lengthened transmission season, particularly during the month of October.

Bourdages and Huard (2010) use a Canadian Regional Climate Model (CRCM) to provide projections for a number of specific locales within Ontario, including Toronto City Centre and Toronto Pearson Airport. They examine three numbers: a long-term trend (1961-

2099, °C/100 years) and two sets of differences between future and reference periods (D1 -1980s vs. 2050s, °C; D2 – 1980s vs 2080s, °C).



(a)



(b)

Figure 1. Potential expansion of theoretical transmission season of malaria under future climate projections based on daily average temperatures under the A2 scenario. Time period [1981-2010] represents historical climate data, and

each subsequent time period accounts for the projected increase in degrees as estimated by the Ministry of Natural Resources (A2 scenario). (a) Blue dotted line represents the lower temperature threshold for *P. vivax* (16°C). The darker shaded area represents the current theoretical transmission season (TTS), and the lighter shaded area represents the theoretical transmission season (TTS) for [2071-2100]. Source of climate normal data: Environment Canada (2014a). (b) Same as for (a) but where the blue dotted line represents the lower temperature threshold for *P. falciparum* (18°C).

Their results depict rises in mean daily mean temperatures, which are expected to increase between approximately 3.5-5.5°C (D1, D2) in both locales. The mean temperature of the warmest quarter (i.e. the three warmest consecutive summer months: June, July, and August) is expected to increase the most in southern Ontario, approximately between 3-6°C (D1, D2), temperatures being slightly warmer at Pearson Airport than in the city centre. Warmer temperatures may not only lengthen potential transmission seasons for malaria, but may also reduce the number of days required to complete the sporogonic cycle, also known as the extrinsic incubation period. Recall that with each rise in degree temperature, the rate of development increases proportionally. Similarly, this effect may influence mosquito development within the water, potentially resulting in greater vector abundance.

One study that examined the effect of temperature fluctuation on development rates of *P. falciparum* determined that areas that experience a significant degree of daily temperature fluctuation actually see reduced extrinsic incubation periods (Paaijmans et al., 2009). In other words, warm temperatures for only part of the day can result in a boost in the development rate of malaria within the mosquito, resulting in fewer development days overall compared to regions where temperatures are warm throughout the day. Therefore, malaria risk could be underestimated in areas where mean daily temperatures are below 20°C. This effect may have implications for spring or fall transmission potential in Ontario. However, during the summer

months when temperatures are steadily higher throughout the day, this effect may reduce transmission potential.

Finally, the annual occurrence of heat waves is expected to increase: an additional two occurrences per year in D1, or an additional four per year in D2 (Bourdages & Huard, 2010). Here, heat waves are defined as 3-day averages of maximum and minimum temperatures of over 33 °C and 20 °C, respectively. Heat waves have the potential to be directly damaging to *Plasmodium* development, 33°C representing the upper temperature threshold for both *P. vivax* and *P. falciparum*. However, the indirect effect of heat waves on humans, and the accompanying heat stress, may increase overall susceptibility to disease (Grieffenhagen & Noland, 2003). Large cities such as Toronto are particularly prone to this impact of climate change due to the ‘heat island effect’, or the greater absorption of heat by surfaces within an urban centre (Grieffenhagen & Noland, 2003).

Precipitation

In the same report, the Ministry of Natural Resources (Colombo et al., 2007) also provide rainfall projections. It is estimated that rainfall may reduce by only 0-10% in southern Ontario, even by 2100. Recall that the minimum level of monthly rainfall required for the availability of standing water and relative humidity for mosquitoes is 80mm for a minimum of four consecutive months (overlapping with the suitable temperature window) (Berrang-Ford et al., 2009). In other words, a minimum total rainfall of 320mm over four months is required. Across southern Ontario, precipitation from April to September has historically been 400-600mm (Colombo et al., 2007). Therefore, although overall reductions in rainfall have the potential to be deleterious to mosquito longevity, a 10% loss in rainfall over the entire warm season does not amount to

much (60mm at most). However, Bourdages and Huard (2010) confirm a decrease in summer precipitation for Toronto City Centre and Pearson Airport, their projections being somewhat greater: a 16-25% reduction in rainfall (D1, D2).

Despite potentially less overall precipitation during the summer in southern Ontario, more frequent extreme rainfall events are expected (Bourdages & Huard, 2010; Colombo et al., 2007). Heavy rainfall events can be in the form of ‘short duration rainfall events’ (50mm or more of rain within one hour) or as ‘rainfall warnings’ (50mm or more of rain expected within 24 hours, or 75mm or more expected within 48 hours) (Environment Canada, 2014b). The frequency of such events may prove to be just as significant as temperature, whereby hot, dry periods separated by heavy rainfall events are thought to be particularly conducive to mosquito abundance (Grieffenhagen & Noland, 2003). For example, in 1999, two cases of locally transmitted malaria were reported in Suffolk County, New York, following a heavy rainfall event which occurred during a particularly hot, dry summer (Bradley et al., 2000). These conditions were thought both to increase mosquito abundance and to reduce mosquito predator populations (Grieffenhagen & Noland, 2003).

The frequency of 24-hour rainfall events may be those most affected in the future, and those events which occur every 50 years may increase in frequency to every 20 years (Bourdages & Huard, 2010). Another study estimated changes in the frequency and amount of future heavy rainfall events for various southern Ontarian cities including Toronto as a means of calculating the monthly total number of rainfall-related water damage insurance claims and incurred losses (Cheng et al., 2012). Their results demonstrated an increase both of claims and of incurred losses of 13%, 20%, and 30% for the periods of 2016-2035, 2046-2065, and 2081-2100, respectively. Although this study specifically examines potential urban flood damage, the overall increased

risk of flooding from such heavy rainfall events may also pose a threat within less built-up environments such as areas outside Toronto's downtown core. In this case, flooding may be advantageous to mosquito vectors in terms of providing additional breeding sites.

However, it is important to note that there is a particularly high degree of uncertainty associated with modelling this type of climate indicator because it is based on extreme events (averaged values). Furthermore, discrepancies between observed (station) data and model simulations must be accounted for, e.g. rain gauges do not record 100% of actual rainfall because in the case of an extreme weather event, high winds can deflect rain from the gauge resulting in reduced observed precipitation extremes (Bourdages & Huard, 2010). In terms of climate modelling in general, natural climate variability (referred to as noise) increases as one focuses in on a regional scale from a global scale. For example, the CRCM and CCGCM are downscaled global models which use data that is interpolated so they are specific to a particular region. Noise also increases when precipitation is examined (vs. temperature), and as we move from mean annual values, to mean seasonal values, to extremes, such as extreme rainfall events.

Consistency with Other Studies

The conclusions drawn from the examination of these climate projections (average temperatures and precipitation, and extreme rainfall events) are consistent with conclusions made by several other studies, although there are few which directly examine changes in malaria risk in relation to climate change in Canada. Duncan (1996) examines the risk of *P. vivax* and *P. falciparum* in the region of Toronto under a climate scenario where the mean daily temperatures are associated with a doubling of carbon dioxide. Using this climatic factor in isolation,

development and transmission of both species of malaria in this region may be possible; however, it is strongly cautioned that other factors may negate or exacerbate this effect.

Griefenhagen and Noland (2003) describe the indirect effects of climate change on vector-borne infectious diseases generally, whereby projected temperatures for Ontario are likely to represent a lengthened theoretical transmission season as well as increased rates of survival, development, and reproduction of insect vectors. Direct effects of climate change are also likely to be detrimental to human health. Much like the effect of heat waves, reduced air quality can also lead to immune system suppression, and increased crowding and the deterioration of sanitary conditions during extreme weather events may increase infection rates (Griefenhagen & Noland, 2003). Although these particular direct effects of climate change are beyond the scope of this paper, it is important that they be recognized.

Malaria is also addressed specifically by Griefenhagen and Noland (2003) where the effects of climate change are believed to include a northward expansion in the range of malaria, increased rates of *Plasmodium* development within the mosquito, and even the drift of infected mosquitoes beyond their normal flight range (which is normally approximately 1.6km for *An. quadrimaculatus*) by means of extreme winds. Griefenhagen and Noland (2003) also describe an expansion of swamp habitats from increased precipitation during the winter months which would then be followed by dry, hot summer periods resulting in outbreaks. Finally, more rain and higher humidity are said to have the potential to boost mosquito abundance, although again, this depends on the degree of overlap with appropriate temperatures.

Berrang-Ford et al. (2009) also summarize several presumed potential impacts of climate change on malaria, this time within the context of Ontario specifically. Based on climate projections for Chatham including increased temperature and frequency of heavy rainfall events,

changes in the seasonality of transmission and in mosquito abundance can be expected for southern Ontario. For example, using archived data from Environment Canada, Berrang-Ford et al. (2009) estimate an increase in the number of consecutive days per year that are over 18°C. In fact, a doubling of the potential transmission season for malaria could occur by 2099. This estimate is even deemed conservative since many of those days represent temperatures well over 18°C such that an overall decrease in the number of necessary consecutive warm days is expected for both *Plasmodium* and *Anopheles* species. However, the risk of malaria becoming endemic in Canada is considered low; rather, sporadic outbreaks are the more likely outcome.

3.4 Conclusion

It is clear that climate projections for Canada, despite some minor variation, describe an overall warming trend along with changes in precipitation patterns which are likely to be conducive to an increase in potential malaria risk in regions where competent vectors already exist, such as southern Ontario. The effect of temperature fluctuation on development rates of malaria within the mosquito may result in some underestimation of transmission potential during the spring or fall months, and some overestimation of transmission potential during the summer. Despite some limitations in terms of climate modelling, particularly in the case of extreme rainfall events, it is clear that the climatic factors discussed here are very likely to result in an increase in the theoretical transmission season for malaria in this area, all other factors aside. Increased development and daily human biting rates, and lengthened vector mating season and lifespan all have the potential to increase malaria transmission potential in southern Ontario.

The degree to which Canada's public health system is capable of handling such an increase is difficult to say. However, this system is already characterized by a number of

inadequacies such as underreporting, and issues in surveillance, diagnosis, treatment, etc., as described in the previous chapter. Therefore, such an increase in malaria risk is particularly worrisome when considered alongside exacerbating factors such as increasing global drug resistance and an increasing number of cases of malaria imported into Canada through immigration and travel. Nevertheless, Canada's fairly strong and adaptable health system, despite its inadequacies, make it improbable that malaria will become endemic to this region. Sporadic outbreaks of malaria are more likely.

It is important to establish that, within a population that has a high susceptibility to malaria, the health outcomes resulting from even sporadic outbreaks may be significant. More importantly, we cannot expect those health outcomes to be evenly distributed throughout all members of the public. In order to move forward with this discussion, it is crucial that we investigate how the social determinants of health (SDOH) might help to explain why certain groups may face greater risk from a malaria outbreak. As such, the goal will be to see how the SDOH model might frame this issue as well as contribute to our understanding of it. The next chapter, '*Urban Health and Population Demographics in the GTA: Uncovering Vulnerability among Immigrant Groups*', will examine the health and population demographics of those groups considered most susceptible to infection from malaria within the Greater Toronto Area, and why they are considered susceptible in the first place.

Chapter 4

Urban Health and Population Demographics in the GTA:

Uncovering Vulnerability among Immigrant Groups

4.1 Introduction

Some groups may face greater risks to their health than others based on socioeconomic factors such as income and social status. These factors are referred to as the social determinants of health (SDOH) and represent a model of health analysis that can tie together all the previous chapters. As promised in the Introduction, a comprehensive discussion of the SDOH will be entered into in this chapter, as it applies to certain vulnerable groups in Toronto. Although this approach to examining health disparities is more commonly associated with chronic health outcomes such as high blood pressure, adult-onset diabetes, risk of stroke, etc., the following discussions will support the case that this model is equally applicable to other types of health outcomes such as communicable diseases. This chapter will explore malaria as a communicable disease and a public health concern in terms of its relevance to SDOH discourse.

In the literature pertaining to general information on malaria, susceptibility to disease is most commonly described in medicalized terms, such as in terms of the degree of immune function and one's immediate physical state as defining one's susceptibility. For example, susceptible groups are, for the most part, limited to young children, travelers, and immuno-compromised individuals such as pregnant women (WHO, 2013a). Griefenhagen and Noland (2003) perhaps come the closest to recognizing the existence of other categories of vulnerable groups in reference to malaria within the context of climate change by acknowledging

vulnerability among Ontarians based on factors such as social and/or economic constraints, occupational exposure, and location (e.g. urban, coastal). Unfortunately, the discussion does not extend beyond that point. A lack of discourse within public health literature on the topic of specific vulnerable groups in relation to malaria (and infectious diseases in general) will be discussed in Chapter 5: *‘Malaria within Climate Change, Infectious Disease, and Public Health Discourse’*.

It is important to remember that vulnerability to malaria may be considered on two temporal scales: the present, where malaria is limited to imported cases, and the near future, where climate change in southern Ontario may result in suitability for local transmission. This chapter will address vulnerable groups who encapsulate the present day scenario, as well as begin to build a case for how this vulnerability may resonate within future climate change scenarios, for example, in the case of local transmission of malaria. Generally speaking, there are many types of vulnerable groups identified by social and economic parameters (i.e. women, visible minorities, low-income individuals). Here we will focus only on one type because of its direct association with malaria. As described in Chapter 3, immigrant populations represent the vast majority of all imported cases of malaria in Toronto and the GTA. As such, it will be useful to examine these immigrant populations more closely using a variety of socioeconomic and health demographics.

This chapter will delineate which are the largest immigrant groups in this area whose countries of origin are endemic to malaria, and who also already face certain health disparities. Through this process, we begin to piece together why certain groups in Toronto may face particular risk when it comes to imported or locally-transmitted malaria. This chapter’s discussion comprises the following: (1) which are the largest immigrant groups in Toronto, and

how representative are they of current immigration trends to Ontario and Canada?; (2) what are the current malaria trends of the countries of origin of these prominent immigrant groups?; (3) what factors make these groups vulnerable in terms of their health?; and (4) what evidence is there that rates of imported malaria in Canada already fall along lines of disparity? Through a careful consideration of all of these questions, it will become evident that certain ethnic origins or immigrant groups already experience a number of challenges which, when aligned, create situations of vulnerability towards imported malaria. Gaining an understanding of these disadvantageous circumstances may then shed some light upon how these groups are likely to face increased risk to malaria in the future.

Finally, the previous chapter on climate projections maintained a broader scope on the area of southern Ontario, necessary due to the fact that climate change trends were considered on a regional scale. Here, the focus will be narrowed in on the GTA because the attention turns to populations within this area. As the following section will describe, the vast majority of immigrants are concentrated within the GTA. It must be noted that population and health demographics, and reports and maps on poverty and immigration are more readily available for the City of Toronto than for the broader GTA (comprising five regions: City of Toronto, Durham, York, Peel and Halton). Therefore, when available, information for the GTA will be included. Otherwise, the majority of the content of this chapter focuses on the City of Toronto, referred to simply as Toronto from this point onwards.

4.2 Prominent Immigrant Groups in Toronto

There is no question that Toronto attracts immigrants. In fact, seven out of ten Ontarian immigrants live in Toronto, and are more likely than their Canadian-born counterparts to live in

large urban centres (Statistics Canada, 2013). Approximately half (49%) of the entire population of Toronto are immigrants. This value is significantly higher than the national rate of 20.6%, and the surrounding GTA rate of 38% (Statistics Canada, 2013). Furthermore, approximately half of all Toronto immigrants are relatively new, meaning they have lived in Canada for less than 15 years (Pinto et al., 2009). New immigrants embody a growing city, whereby the population (2.5 million in 2006) is expected to reach 3.3 million by 2036 (Ontario Ministry of Finance, 2009).

Where are these immigrants coming from?

For over a decade, the most important source countries to Canada have been and continue to be China, the Philippines, and India (Citizenship and Immigration Canada, 2012). Toronto receives a vast share of these individuals, 30% of Canada's new permanent residents in 2012. The face of Toronto is changing to reflect a shift in immigration trends. The majority of immigrants arriving in this province are now from Asia and the Pacific (over 50% in 2012) and Africa and the Middle East (22% in 2012), rather than from Europe which has historically represented the greatest source for immigration (Citizenship and Immigration Canada, 2012). In terms of Toronto immigration specifically, several countries are particularly noteworthy: China, India, Philippines, Pakistan, and Sri Lanka. Combined, these countries represented nearly half of all immigrants who arrived between 2001 and 2006 (Khandor & Koch, 2011).

These immigration trends are strongly reflected in the composition of visible minorities in Toronto, who also comprise half the population. The top three visible minority groups are South Asian (12% of the population), Chinese (11%), and black (9%) (Statistics Canada, 2013). Please note that the black minority group is not broken down further into ethnic origins and would thus include African and Caribbean visible minorities. A total of 2.6 million visible minorities reside in the GTA, a number that accounts for 47% of all visible minorities in the

country. It is clear that Toronto is strongly characterized by its immigrant communities. More importantly, these figures represent a trend that is expected to increase. South Asian, Filipino, and Latin American groups are considered the fastest-growing visible-minority groups in Toronto, (Khandor & Koch, 2011).

Statistics Canada categorizes children of immigrants born in Canada as ‘Canadian-born’, a classification that is certainly appropriate in and of itself. However, it also means that those children of immigrants are not included or accounted for in their corresponding immigrant grouping. They would, however, be accounted for under visible minority or ethnic origin groupings. Therefore, it is perhaps more relevant to use ‘multi-generation immigrant’, ‘ethnic origin’ or even ‘visible minority’ as descriptors to define at-risk groups in Toronto because it allows one to account for children born in Canada but who still live with immigrant parents or family members, or who live within a broader immigrant community.

Logically speaking, the risk of acquiring a malarial infection abroad are strongly linked to the ethnic origins of one’s family and/or community because these factors are to some degree demonstrative of the likelihood of travel back to malaria-endemic countries of origin. Furthermore, it is also linked to exposure to malaria while abroad since families returning to their country of origin are more likely to stay longer and visit rural areas than Canadian-born tourists, thus increasing their risk of infection (K. Kain, personal communication, June 5, 2014).

As evident from the figures discussed above, several ethnic groups in Toronto stand out in terms of sheer population. So, those whose source countries represent regions where malaria represents a public health concern are the most relevant to consider with respect to malaria risk here in this region: Chinese, Filipino, South Asian, and African (multiple regions). Please note that for simplicity’s sake, immigrants of African origin will be grouped together due to the fact

that the majority of countries in the African continent face some degree of malaria risk.

Similarly, South Asia will represent a grouping of core countries (Bangladesh, India, Sri Lanka and Pakistan) where malaria is a concern.

4.3 Linking Ethnic Origin to Malaria Abroad

In deciding which ethnic origins within Toronto and the broader GTA are most worthy of consideration in this discussion, one must determine to what degree malaria is an issue abroad.

As discussed in Chapter 3, global trends of malaria may be highly influential in determining rates and species of imported malaria here in Canada (Maclean et al., 2004). Immigration trends are indicative not only of imported malaria risk, but also of the possibility of travel to and from such malaria-endemic regions.

The WHO World Malaria Report (2013b) details the current malaria status of entire regions as well as individual countries where malaria represents a public health concern. The regions described by the WHO which are also relevant to the discussion here include Africa (West, Central, and East/Southern Africa), South-East Asia, and the Western Pacific (includes China and the Philippines). The report also includes the prevalence of each *Plasmodium vivax* and *Plasmodium falciparum* species of malaria for each country, this owing to the fact that they are the most common types of malaria worldwide.

To begin with South-East Asia and the Western Pacific, certain countries in these regions may already be seeing trends towards the elimination of malaria, particularly China, India, and the Philippines. Yet, there are still significant populations living in areas at risk of malaria in these and other countries in the region (WHO, 2013b). For example, overall in South-East Asia, there are still 1.6 billion people at some risk of malaria and 1 billion people at high risk of

malaria. However, one must also account for the distribution of risk within these areas and the populations therein. For example, malaria is particularly centred in the Yunnan province of China, but incidence occurs mostly in highly forested areas and also disproportionately affects ethnic minorities and migrants. It could then be speculated that since malaria risk in China appears to be situated for the most part in more remote areas, the risk of being imported back to Canada is less than if the disease were more prevalent in city centres. This assumption is based on the fact that urban areas simply have greater populations from which immigrants may be sourced. Finally, the presence of falciparum malaria is more prevalent than vivax in China, Bangladesh, and the Philippines. Elsewhere in South-East Asia and the Western Pacific, it represents at least 30% of all cases, with the exception of Pakistan and Sri Lanka. In terms of the risk of imported malaria, falciparum is certainly more of a public health concern considering its association with severe malarial infections.

Africa is another situation altogether where significant proportions of each area are at some risk as well as at high risk of malaria. For example, 324 million people are at some risk of malaria in Western Africa alone. Considering that the population of the entire continent is just over one billion, these numbers hold significant weight. Furthermore, falciparum is highly predominant in every region. However, accurately assessing malaria trends represents a challenge in every region in Africa due to ongoing changes in several areas of the health sector such as ability to access services, diagnostic testing, and reporting.

This brief examination of the likelihood of immigrants or tourists acquiring a malaria infection in an endemic country or region and importing it back to Toronto represents risk that is external to Canada. In summary, South Asia and particularly Africa represent regions abroad where malaria is a significant public health priority not only in terms of populations at risk, but

also in the prevalence of falciparum malaria. Due to the predominance of these particular multi-generation immigrant groups in the GTA, these external risks merit significant consideration when assessing risk here in this region. Let the discussion now turn to those internal factors which create vulnerability among these same groups in Toronto with respect to overall health and well-being, vulnerability which may be indicative of susceptibility to infectious disease today, and in the future.

4.4 What Makes These Groups Vulnerable in Toronto?

Low Income

The link between immigrant communities and low-income areas in Toronto is no coincidence. The *Profile of Low Income in the City of Toronto* (City of Toronto, 2010) is a report that delineates Toronto's low income demographics in 2006, and discusses income trends during the period leading up to and subsequent to this date. Although Canada has no official definition of poverty, low income in this case is defined by Statistics Canada's Low-Income Cut-Offs (LICOs) or the Low Income Measure (LIM). LICOs represent income thresholds below which individuals or families are considered to spend more than the average amount of income on food, shelter, and clothing, e.g. more than 20% (Statistics Canada, 2009a). The LIM represents 50% of the median adjusted family income in Canada, where adjustments are made for family size only and not for other factors such as location (Statistics Canada, 2009b). Within Toronto, the issue of poverty is particularly prevalent, and is a growing concern. Not only are more people becoming poor, but low-income rates are nearly twice as high as those for the rest of the GTA, Ontario, and Canada (Pinto et al., 2009).

As is made clear in this same report, the issue of low income greatly affects immigrants in Toronto, who accounted for 57% of all individuals in 2006 living below the LICO (before tax). Furthermore, certain subcategories of immigrants face a disproportionate risk, such as recent immigrants. In this particular report, recent immigrants are described as those who arrived to Canada between 2001 and 2006. Within this group, 46% were categorized as low income. The report also posits that the longer immigrants reside in Canada, the less likely they are to be low income. For example, the low income rate in 2006 among those who arrived prior to 1991 was only 19%, a rate more comparable to that of non-immigrants. It has been suggested that it takes, on average, approximately 10-15 years for immigrants to achieve the income level of non-immigrants (City of Toronto, 2010).

When breaking this down into specific ethnic groups, the difference between European and non-Europeans (and thus predominantly non-visible minorities and visible minorities) becomes all the more obvious (see Table 1). This incidence of low income among immigrant populations in Toronto must then be considered in its contribution to the vulnerability of these groups. Finally, women, single parents, and the elderly who live alone are all considered high-risk groups with regard to poverty. (Raphael, 2011). Therefore, immigrants who also fall under one of these high-risk categories are likely to be particularly disadvantaged. As will be discussed later on, the issue of a lack of material and social resources is highly intertwined with issues pertaining to health.

Ethnic Origin	Low Income Rate (%)
West Asian	46
African	46
Arab	36
Latin, Central, and South America	31
South Asian	31
Caribbean	30
Aboriginal	30
East and South Asian	29
European	17
British	15

Table 1. Low income rates among ethnic groups in Toronto in 2006 demonstrating disproportionately high rates among non-European origins. Source: The Profile of Low Income Profile in the City of Toronto (City of Toronto, 2010).

Location

Generally speaking, the distribution and concentration of human populations are strong determinants of the spread of infectious disease. In the case of malaria where it is not being spread from person to person directly, the focus becomes: (1) the number of potentially infective individuals in the area, and (2) the capacity for the surrounding environment to support mosquito vector populations. In terms of the future threat of sporadic local malaria outbreaks, entire communities may face risk. This section will focus on the first point by examining how the distribution of these specific groups within the GTA might be considered problematic in terms of increasing malaria transmission risk in the future. Again, today, all cases of malaria are imported by individuals and are then processed by the public health system here. Only one case of locally transmitted malaria has been reported in our recent history in Toronto (Baqi et al., 1998).

On the whole, recent immigrants tend to settle in the northern and eastern parts of Toronto, i.e. North York and Scarborough (Khandor & Koch, 2011). If we were to examine the distribution of overall immigrant populations or visible minorities within Toronto, a distinct ‘U’

pattern emerges, along with significant concentrations in the northwest and northeast particularly (see Figure 2). Although the municipality of Toronto itself comprises substantial populations of visible minorities, certain surrounding municipalities have more. In fact, 85.1% of all visible minorities in the GTA are located within four municipalities: Toronto, Mississauga, Brampton, and Markham, whose proportions of visible minorities are 49.1%, 53.7%, 66.4%, and 72.3%, respectively (Statistics Canada, 2013).

When examining population distributions of individual minority groups in the GTA, members of Chinese ethnic origin appear to cluster most in the northeast quadrant of the municipality of Toronto as well as having particularly high densities in Markham. Filipino communities appear to be, on the whole, less concentrated in any one area, although significantly large communities exist in Mississauga, Brampton, Vaughan, Markham, and of course within Toronto, particularly the northeast quadrant. South Asian communities are highly concentrated in Mississauga, Brampton, Markham, and the northwest and northeastern portions of Toronto. African communities tend to be on the whole more spread out throughout the GTA, although large populations are concentrated in Brampton, and the northeastern and northwestern portions of the municipality of Toronto. In summary, Mississauga, Brampton, Markham, and northeastern and northwestern quadrants within Toronto represent areas where high numbers of Chinese, Filipino, South Asian, and African visible minorities all reside. These areas may represent risk zones for malaria transmission under future climate change scenarios.

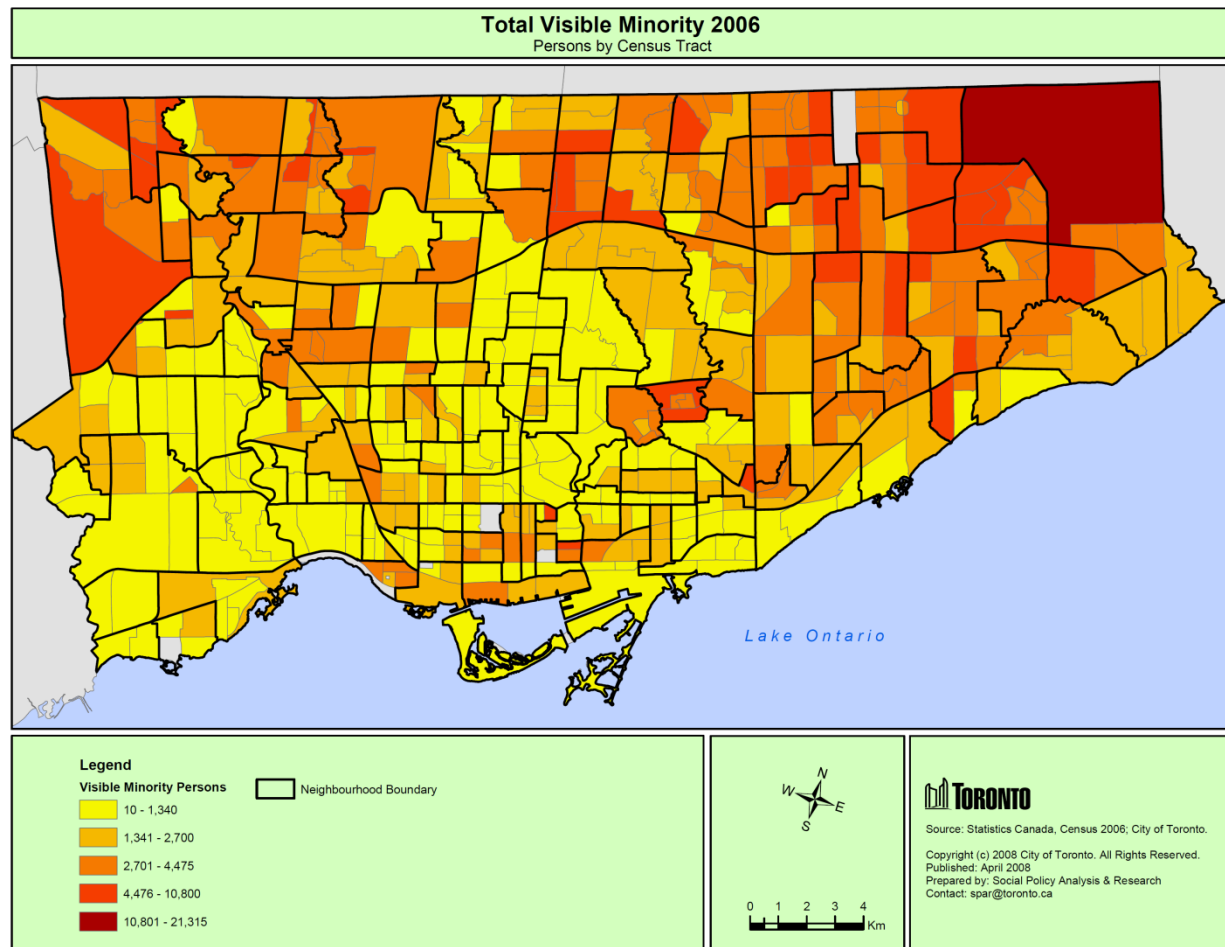


Figure 2. Visible minority population distribution in Toronto. Reprinted from Toronto Social Atlas, In City of Toronto, Social Policy Analysis & Research. Retrieved April 20, 2014, from <http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=ce2e186e20ee0410VgnVCM1000071d60f89RCRD&vgnextchannel=1e68f40f9aae0410VgnVCM10000071d60f89RCRD#6>. Copyright 2007 by City of Toronto. Reprinted with permission.

More important, however, is the conspicuous pattern of the settling of recent immigrants in low-income neighbourhoods in Toronto. Referred to as ‘Priority Areas’, these neighbourhoods are characterized by high rates of unemployment and low incomes. Ten of Toronto’s thirteen Priority Areas are overrepresented by recent immigrants (McKeown et al., 2008). The *Newcomer Health in Toronto* report (Khandor & Koch, 2011) also shows that at least one if not two or more

of the following countries appear among the ‘top five places of birth’ in Priority Area neighbourhoods: China, the Philippines, India, Sri Lanka, Pakistan, Nigeria and Guyana.

There is also strong evidence of growing inequality between wealthy neighbourhoods and poor neighbourhoods, with the former increasing in wealth and the latter declining (Hulchanski, 2010). Recent immigrants are four times as likely to live in a poor, declining neighbourhood than in an increasingly wealthy neighbourhood (City of Toronto, 2010). The link between the level of development of a neighbourhood and potential future malaria transmission may be considered in terms of immediate risk and exposure (quality of housing, properly fitted screens, etc.) as well as being representative of other determinants of health (low income, poor nutrition, etc.) which may increase overall susceptibility to worse health outcomes.

Environmentally speaking, poorer neighbourhoods are also much more likely to be unhealthy. For example, the distribution of National Pollutant Release Inventory (NPRI) facilities closely matches the distribution of poverty in Toronto (PollutionWatch, 2008). The output of air pollutants in these areas almost certainly contributes to the poor health of nearby residents. To conclude, environmental contaminants, quality of housing, and poverty in general may all be used to map vulnerability to poor health in Toronto and the GTA. Therefore, it may not come as a surprise that immigrants and visible minorities in Toronto already face considerable risk with respect to certain infectious diseases. These, in turn, may create a greater overall susceptibility to other health threats such as malaria.

Tuberculosis and HIV/AIDS

Tuberculosis (TB) has disproportionately affected foreign-born populations in Canada for a number of years (Toronto Public Health, 2012; Zaidi, 2014). Over the past decade, a high

proportion of immigrants entering Canada have arrived from countries with high rates of TB, and among those arriving, half may already have a latent TB infection (LTBI) or be to some degree at risk of infection (Gushulak & Martin, 2007). In Ontario, immigrants represent approximately 90% of all cases (MOHLTC, 2009), which are highly concentrated within the GTA (Zaidi, 2014). In Toronto, an even higher proportion of active cases of TB affect immigrants (Khan et al., 2011; Toronto Public Health, 2012), and these cases tend to be reactivated LTBI (Khan et al., 2011). Certain conditions such as substance abuse, malnutrition, poor sanitation, poverty, and other diseases have the capacity to reactivate LTBI (Reitmanova & Gustafson, 2012).

Considering the link between these compromising conditions and TB reactivation, it may not be surprising to discover that 42% of all new active TB cases among Toronto immigrants between 2006 and 2010 affected those who had lived in the country 10 years or more (Khandor & Koch, 2011). It now becomes increasingly evident that the burden of TB in Toronto must not be solely attributed to the importation of TB by new immigrants, although the initial acquisition of the disease most likely occurred abroad. Rather, a significant proportion of cases are reactivating long after these immigrants have settled here, confirming that these groups are exposed to significant risk with regard to low income or other risk factors.

In 2012, the most reported exposure setting (the location where the infection was most likely acquired) was linked to travel to or residence in an endemic area, a setting that accounted for 96% of cases in Toronto (Toronto Public Health, 2012). In terms of cases of TB among foreign-born populations, the top countries of birth represented among these patients are the Philippines (55% of foreign-born cases), India (43%), and China (36%) (Toronto Public Health, 2012). Similar to malaria, these rates of TB in Toronto are also thought to mirror rates of TB abroad (Toronto Public Health, 2012). Finally, in terms of distribution of TB incidence within

this region, about 73% of Ontarian cases occur within three health units: Peel, York, and Toronto (Zaidi, 2014). Cases of TB within the municipality of Toronto occurred in 78% of its neighbourhoods in 2012, exhibiting a widespread distribution for the most part, although the northeast region of the municipality appeared more affected (Toronto Public Health, 2012).

HIV/AIDS, Ontario's sixth most burdensome disease, is another problem that is an increasing problem among immigrant populations in Toronto and in Canada, although considerably less so than TB. Immigrants arriving from HIV-endemic regions such as Sub-Saharan Africa and the Caribbean are particularly affected. In 2010, 11% of new cases of HIV affected immigrants from HIV-endemic countries. Although HIV is less of an issue among Chinese, South Asian, and Filipino groups, it does represent a significant concern for African immigrants. Tied into this is the issue of co-infections. Co-infections of HIV and TB represent a considerable health risk in that both diseases are immunosuppressant and work synergistically in the deterioration of one's health. Furthermore, HIV/AIDS is considered a high risk factor for activation of LBTIs (Long & Boffa, 2010). Fortunately co-infections are not very common at this time in Toronto; i.e., only 2% of TB cases were co-infected with HIV in 2011 (Toronto Public Health, 2012). That said, immigrants do face a greater risk of acquiring co-infections in Canada (Phypers, 2008).

Social Determinants of Health for Immigrants

What factors compromise the health of immigrants in the GTA, in turn creating susceptibility to infection from communicable diseases? Let us revisit the social determinants of health (SDOH) model, which is highly applicable and relevant when it comes to the health of these groups, particularly in a location such as Toronto. The SDOH represent the social and

economic conditions which both directly and indirectly affect the health and wellbeing of individuals (McKeown et al., 2008; Raphael, 2002). Rather than viewing health as a result of one's immediate social and material resources, the SDOH model considers factors that tend to cluster around social or material disadvantage, both in the short term and over the life-course. For example, financial insecurity has clear direct effects on health, such as the resulting food insecurity which has the ability to impact one's overall health due to the risk of poor nutrition. However, the situation of low income families in Canada also tends to be associated with a lack of social connectivity, fewer educational opportunities, poor housing, and unstable working conditions (Raphael, 2011). The psychosocial effects of any combination of these stressful factors can have significant physiological impacts on the body, thus compromising the overall health of an individual (Raphael, 2002). One of these impacts is interference with immune function (Locker, 2008). When it comes to malaria risk, this is clearly important.

Certain groups within Canadian society are more likely to experience these impacts. As discussed at length in the previous section, immigrants, particularly recent immigrants, face a disproportionate risk of low-income situations in Toronto upon their arrival to Canada and even years afterwards. This problem is reflected in the distribution of immigrant populations in low-income neighbourhoods in Toronto, as well as in other ways such as in the demographics of food bank users in Toronto, 47% of who are immigrants (Khandor & Koch, 2011). This reality is simply one facet of the societal barriers immigrants to Canada must face. From a material perspective, the ability to secure employment that is reflective of their credentials, or even their ability to secure stable employment at all, may be severely hindered. This problem is also referred to as the 'Canadian experience' and is heavily tied to the issue of discrimination against foreign-born individuals who are also visible minorities (Khandor & Koch, 2011). As a result,

immigrants may be more likely to take on precarious work, longer hours, multiple jobs, etc. (Raphael, 2011). These limitations may then be reproduced in that individual's perceived place in society, affecting self-esteem, sense of self-worth, etc.

The process of racialization, when combined with the many typical challenges involved in adapting to a new country and way of life (e.g. barriers in accessing services, language barriers, etc.), prevents individuals from realizing not only their full economic and societal potential, but can also have repercussions for their health and well-being. In the report, *Racialization and Health Inequities in Toronto* (Toronto Public Health, 2013), the Ontario Human Rights Commission's (2005) definition of 'racialized' is used and defined as "the process by which societies construct races as real, different and unequal in ways that matter to economic, political and social life". Among those immigrants who arrived in Toronto between 2001 and 2006, 81% identified themselves as belonging to a racialized group (Khandor & Koch, 2011). In the study performed by Toronto Public Health (2013), a strong link was found between the experience of racial discrimination and self-rated health, whereby this particular experience causes stress and has the capacity to affect one's immune, endocrine, and cardiovascular systems. Among the participants of the study, 67% had experienced some form of discrimination based on their race, ethnicity, or culture (Toronto Public Health, 2013).

As a result, the stress associated with living as a visible minority immigrant in Canada is connected to disproportionately high rates of poor health outcomes for these groups. When they arrive, immigrants are said to have the 'newcomer health advantage' in that they are more likely to be young, as well as healthy due in part to a higher level of motivation among those individuals who go through the laborious process of emigration, as well as to Canada's own immigration screening process (Khandor & Koch, 2011). However, this 'advantage' is said to

deteriorate the longer those individuals reside here, and the rate of deterioration may be faster for particular subpopulations such as women, the elderly, and lower income groups (Khandor & Koch, 2011). In terms of chronic disease (e.g. high blood pressure, diabetes), low-income and non-European groups face a higher risk than others (Khandor & Koch, 2011). With respect to infectious diseases, TB rates among immigrants in Toronto have already been discussed; recall the connection between poverty (along with its associated poor and crowded living conditions, malnutrition, etc.) and LTBI reactivation.

The evidence of health inequalities experienced by immigrants and visible minorities in Toronto is clear, with poor health strongly linked to situations of poverty, discrimination, and disadvantage in terms of both material and social resources. Having looked at the SDOH model as it applies to TB, HIV, and health in general, we should now examine to what degree malaria incidence is determined by social factors. *The Communicable Diseases Report in Toronto* (Toronto Public Health, 2012) is the most recent publication presenting data on malaria within this municipality. In terms of the number and proportion of reported cases for all reportable communicable diseases in Toronto, malaria is ranked 21st. For the purpose of comparison, TB ranked 15th, and HIV ranked 10th. Among four vector-borne and zoonotic diseases, malaria ranked 2nd after West Nile Virus illness, but before Lyme disease and rabies, with 87 cases of malaria in Toronto in 2012. It must be maintained that this number may very well be an underestimate: recall in Chapter 2 that the Public Health Agency of Canada (2004) reported that national figures on malaria incidence may only represent 30-50% of actual cases. In terms of health demographics pertaining to malaria incidence in Toronto, only sex and age at onset are described. No data regarding income, social status, or ethnic origin is included. For this reason, it is important to turn to academic publications in seeking this information.

4.5 Malaria as a Social Disease in Canada

There is evidence that the incidence of imported malaria in several major Canadian urban centres may already fall along lines related to social and economic inequality (Eckhardt et al., 2012; Lee et al., 2013). A study performed in Calgary over the 11-year period from 2000 to 2011 concluded that the highest incidence of malaria fell mostly within the northeast quadrant of the city, an area characterized by increased immigration, lower education, and lower average income. These factors were thought to influence the likelihood of accessing the health system to acquire prophylaxis, thus resulting in an increased probability of acquiring malaria while travelling (Lee et al., 2013). The results of the study showed that the top three travel destinations among those who had contracted malaria abroad were Sudan, India, and Nigeria, and the greatest number of cases of malaria originated in those same countries, as well as in Uganda, Ghana, and Cameroon. Furthermore, the incidence rate of malaria nearly doubled over the study period observed, an increase that was representative of an increasing trend of imported malaria tied to immigration trends.

A similar study was carried out over one year (2008-2009), and covered the entire province of Ontario: it was found that not only were case patients who lived in neighbourhoods with a high proportion of immigrants 17 times more likely to acquire and import a malaria infection, but they were also more likely to be male and live in a low-income neighbourhood (Eckhardt et al., 2012). Since this study was performed over a much shorter time period, it was not possible to glean any trends from the data. However, Eckhardt et al. (2012) did posit that an increasing amount of international travel and immigration could present a developing health threat with regard to autochthonous (local) transmission in this region. Although all cases of malaria in Ontario were considered at the start of this study, a subset for the GTA was later

created due to the fact that 84 of the total 94 positive cases fell within this region. Reflecting strong immigrant population growth in the areas outside of Toronto, case-patients were more likely to live in suburban areas than in the downtown core. Notably, the region near Pearson Airport and the town of Brampton reported an incidence of malaria 3.5 times greater than other areas. There was also some clustering of incidence in low-income suburbs east and west of downtown, suburbs with high representations of immigrants from malaria-endemic countries. Finally, similar to Calgary, over 94% of recorded travel history among case-patients included Asia, but even more so, Africa. Once again, falciparum malaria represented the dominant species.

4.6 Conclusion

Immigrant and visible minority groups in Toronto and the GTA represent vulnerable populations with respect to overall health and well-being, attributable to certain social and economic factors such as income, social status, visible minority status, etc. The evidence comes in the form of overrepresentation within low income neighbourhoods and in terms of poor health outcomes, such as TB burden associated with immigrants in the GTA. Where malaria risk is concerned, certain subpopulations have been selected here as priority groups based on a number of criteria: numbers of immigrants and immigration trends within the region, the tendency for those groups to live in certain areas within the GTA and the corresponding high association between immigrant neighbourhoods and low-income neighbourhoods, the degree of malaria risk within their source countries, the likelihood of living in a low-income situation and the corresponding degree of vulnerability, and the disproportionate burden of both chronic and infectious diseases (particularly TB and HIV). Chinese, South Asian, Filipino, and African

communities living within the GTA fit all the above criteria with regard to groups at risk of malaria as it is acquired abroad and imported. South Asian communities face particular risk due to high rates of endemic malaria within source countries in this region. As well, African communities also represent a high-risk group based on the extraordinary prevalence of malaria in Africa, as we have seen in the overrepresentation of African-sourced cases of imported malaria already in Canada. Furthermore, in terms of future risk to locally transmitted malaria, the growing issue of HIV and high rates of poverty within this group are sure to create conditions of susceptibility to not just infection, but to overall worse outcomes from that infection.

Although malaria is not yet a prominent public health concern in this region or even in Canada, immigration trends describe an increase of imported malaria, with a predominance of falciparum malaria over vivax. This trend must not be downplayed as they are likely to be underreported. This, combined with recent documentation of incidence of imported malaria falling along existing lines of social and economic inequality in the GTA (Eckhardt et al., 2012) and Calgary (Lee et al., 2012), provides strong evidence for considering malaria as yet another example of a poor health outcome disproportionately experienced by certain groups within our society. This also begins to build upon the idea that not only should factors regarding exposure be taken into account when assessing malaria risk, but also factors pertaining to social and material advantage.

It might be useful to begin thinking about malaria as a social disease, along with TB and HIV, as well as considering it as an indicator for other emerging infectious diseases related to climate change. Furthermore, increasing disease burden among already vulnerable groups may very well exacerbate issues of inequality as they sit within the context of Toronto and the GTA. Before moving on to fully assess how this might play out under future climatic scenarios, it is

important to first evaluate the salience of this issue within conversations at the municipal or provincial level. This will form the basis of Chapter 5, 'Malaria within Climate Change, Infectious Disease, and Public Health Discourse'.

Chapter 5

Malaria within Climate Change, Infectious Disease, and Public Health Discourse

5.1 Introduction

An increase in new, emerging, or re-emerging (NERE) infectious diseases as a result of changing temperature and weather patterns are but one of many predicted impacts of climate change in southern Ontario. This potential impact has been recognized at all levels of government in literature on climate change and health, and climate adaptation, as representing a serious concern for the health of Canadians. However, discussion on malaria specifically is scant, and certain other climate change impacts, such as heat stress or severe weather events, appear to take precedence over discussion on disease in general.

In the wake of both SARS and H1N1 outbreaks in the Greater Toronto Area (GTA), several policy changes in the realm of infectious disease were implemented by the province of Ontario. Ideally, these changes would also encourage the prevention of other climate-sensitive or vector-borne diseases such as malaria. Here we will explore how the priorities and commitments established within these policies and programs set the stage not only for dealing with future NERE infectious diseases as a public health risk, but also how they dictate the application of the SDOH within general infectious disease discourse. What this means for susceptible populations specifically is the main consideration here.

Next, what considerations of resilience might be made in terms of our ability to deal with the impacts of climate change on health? What additional stressors might be applied to a public health system already characterized by a number of inadequacies with regard to infectious

disease prevention, control, and management? The potential for existing health inequalities, and their accompanying economic and social costs, to be exacerbated due to climate change will be considered.

This chapter will go on to explore malaria specifically on a municipal level. The presence of re-emergent malaria as a potential impact of climate change and of the degree of recognition and understanding of the issue as it appears today (imported malaria), will be examined within discourses on climate change, infectious disease, and public health. Ideas and themes expressed in interviews conducted with several prominent infectious disease specialists and clinicians and with municipal health policy experts will supplement this discussion. This information will help to establish what types of gaps exist in dealing with imported malaria today in the GTA and its consideration in the future. From this, we may be able to make projections on the level of salience of malaria, and climate-sensitive infectious diseases in general, on a municipal level as well as on a broader national scale.

Throughout this discussion, it is important to ask the question: ‘How well do proposed actions or strategies on this topic reflect supposed priorities on malaria and climate-sensitive infectious diseases, particularly with regard to certain vulnerable subpopulations?’ As with the discussion on post-SARS/H1N1 Ontario, consideration of the social determinants of health (SDOH) as they are applied within proposed action will be examined. Here, it is important to finish with a consideration of the barriers which may prevent appropriate action from taking place, such as those larger economic and political forces which already influence the degree of health inequality today in Canada and in the GTA.

5.2 Methods

Ideas and perspectives on malaria as an imported disease, as a potentially re-emergent disease, and the role of the SDOH in municipal climate change policy, and infectious disease research and policy were drawn from informants through semi-structured interviews. These informants included three infectious disease experts who worked both as researchers and as clinicians, and two municipal level public health experts in the realm of infectious disease and climate change policy. As such, interviewees fall into two groups which, for simplicity's sake, will now be referred to as 'infectious disease' and 'health policy'. However, it must be clarified that there is some degree of cross-over in terms of the areas of focus of several individuals. For example, one might perform research on climate-sensitive diseases, but also collaborate on work being done on health policy. These individuals were selected based on their potential to provide valuable insight into the topic of malaria as a health concern in the GTA, today, or in the future. However, the intent of this process was also to better understand the role of the SDOH within these fields both in theory and application, as well as to identify the potential barriers that may prevent positive work from happening. Questions were adjusted between the two groups of interviewees so as to gather information that best reflect their areas of expertise. This content will supplement two sections in this chapter: 'Malaria within Climate Change and Health Discourse' and 'Barriers to Change'.

5.3 Ontario's Response to Disease Outbreaks

The H1N1 pandemic hit in 2009, and the Ontario Health Plan for an Influenza Pandemic (created in response to SARS in 2004) was implemented successfully. The province was in a better state of preparation compared to the SARS outbreak: there were fewer deaths in Ontario

than both national and US rates, and even fewer deaths than the seasonal flu average (128 vs. 300) (King, 2010). However, there was still room for improvement and priorities continued to be focused on enhancing coordination and communication among health care units as well as on prevention (King, 2010; King, 2013). Most importantly, Arlene King, the Chief Medical Officer of Health (CMOH) at the time, made a point of recognizing in the discussion of her *2009 Annual Report to the Legislative Assembly of Ontario* the fact that nearly 88% of the victims who died from H1N1 in Ontario all had at least one underlying medical condition, and that nationally we saw a similar picture (King, 2013).

It is clear that there was room for positive policy change in this area, particularly with regard to the acknowledgement of vulnerable groups suffering from a disproportionate burden of poor health outcomes. Promisingly, King (2013) stated in her 2011 report the need for government-wide, intersectoral collaborative efforts as a method for reducing the disproportionate infectious disease burden and premature death among particular groups. The amendments in 2011 to the Health Promotion and Protection Act of 1990, allowed the CMOH greater authority to direct Ontario's boards and medical officers of health. Unfortunately, King's proposed actions remain fixed on improving disease control practices such as vaccine development rather than actualizing any sort of health equity agenda.

In this report, and within the vast majority of government literature on infectious disease, the term 'prevention' is used in the most immediate sense of the word. It may be useful to pause here so that we may fully recognize the use of the word 'preventative' as this paper intends it to be used. In the context of health policy, we must assess to what degree such policies and programs are proactive; that is, do they recognize the SDOH? If so, are the recommended actions reflective of this? Within this context, 'preventative' could be thought of as a means of

addressing the root causes of the disproportionate burden of infectious diseases on certain groups within the GTA. In other words, it means asking what can be done to reduce these groups' vulnerability from the start (i.e. through social and economic improvements that directly tackle health inequalities), rather than simply targeting at-risk groups with educational programs, or by prioritizing surveillance, reporting, and treatment.

Generally speaking, preventative policy on infectious disease tends to be geared towards public education on infection control measures and early identification and management of diseases such as tuberculosis (TB) (OAHPP Act, 2007). An example of this during the post-SARS period was a strong push for immunization and proper hygiene practices (e.g. the 'Just Clean your Hands' campaign) (Ontario Expert Panel on SARS and Infectious Disease Control, 2004; Williams, 2009). Creating and adhering to specific standards and guidelines for controlling and managing disease outbreaks within Ontario's health facilities became a very strong focus of the provincial government after SARS and H1N1 (MOHLTC, 2013).

To conclude, the years following the SARS and H1N1 outbreaks represented opportunities in Ontario's public health history where effective policy change could have taken place with respect to health equity among its citizens. This is particularly true in the case of H1N1 where such a disproportionate percentage of victims had underlying medical conditions. On the whole, although the SDOH and vulnerable groups were recognized, appropriate policy recommendations were never truly made, let alone carried out. It is important to note that this paper does not aim to disregard or dismiss the value of education, vaccination, screening, surveillance, reporting, and treatment (all activities which are crucial in effective infectious disease management); it is when all efforts are focused entirely on those activities that the greater root causes of such health inequalities are disregarded, overlooked, or dismissed altogether. At

this point we may begin to consider how malaria and other NERE infectious diseases fit into this conversation. How might health priorities focusing on surveillance, control, and education set the stage for dealing with future outbreaks, particularly when certain subpopulations face disproportionate risk? This question will be addressed in the sections that follow.

5.4 National Climate Change Vulnerability

Several predicted impacts of climate change are considered indiscriminate, in that all members of the public face a certain degree of risk. However, when we examine these impacts more closely, it becomes clear that although all may face risk, certain groups will feel that impact more deeply in terms of their ability to cope. In a context where, from the start, there is a non-prioritization of these groups in terms of reducing their vulnerability, there is no question that the costs of climate change, both societal and economic, will be extensive.

In the advent of climate change, many stressors may affect us, thus increasing our vulnerability. For example, an influx of environmental refugees into Canada could exert significant pressure on our health infrastructure, in turn hindering the nation's ability to meet the needs of its own marginalized populations. This might also represent an increase in the rates of imported diseases including malaria. The impacts of climate change can also have direct effects on the health of vulnerable groups, such as in the case of an increased number of heat waves and heavy rainfall events, as well as indirect effects such as job loss. These indirect effects may be accompanied by negative health outcomes as a result of stress, potentially further increasing susceptibility to disease. The degree of resilience at the individual level includes not only immediate economic resources but also cultural (e.g. education) and social resources (e.g. family and friends) (Pinto et al., 2009). In the GTA, McKeown et al. (2008) clearly demonstrate the link

between poor health outcomes and low-income groups in the city. When we apply a situation of climate change, the health and well-being of these groups will be at a clear disadvantage in terms of their ability to receive and cope with climate change impacts due to the numerous challenges they already face, and they no doubt will suffer more deeply.

The extra burden on our nation's infrastructure may be considered in the most immediate economic terms, such as costs attributed to injury and illness. However, there are also social costs such as the reduced ability for low-income or marginalized groups to participate fully in society as well as contribute to it. Although climate change adaptation measures which directly address the different needs of these groups in the GTA are necessary, they also represent a short-term strategy. Reducing vulnerability from the start would represent vast social gains and minimize the economic losses.

Unfortunately, there is not even an existing national strategy that addresses the impacts of climate change on the health of Canadians. Since this issue is diffused over multiple levels of government and their corresponding responsibilities, no one level or sector is required to take ownership; some may lack the resources to do so. As a result, a coordinated plan that brings municipalities and provincial/territorial and federal governments together has never materialized. On a local scale, criticisms were made by Pollution Probe of the Toronto-Niagara region's health infrastructure in terms of its capacity to 'anticipate, plan for, and eventually cope with the impending health problems' resulting from climate change (Pollution Probe, 2002, p. 7). In particular, they identified a lack of consideration of the potential for more concentrated outcomes within urban areas as compared with the broader geographic region.

5.5 Malaria within Climate Change and Health Discourse

Government Literature on Malaria and other NERE Diseases

Climate change aside, all provinces have legislated authority to coordinate infectious disease prevention and control programs. This is due to the fact that health falls under the provincial mandate. However, federal, provincial/territorial, and municipal governments all have unique responsibilities with respect to infectious disease. As became clear within the discussion above on SARS and H1N1, the province of Ontario is primarily responsible for activities that revolve around disease monitoring and surveillance, management, education, and ‘prevention’ (i.e. immunization strategies, outbreak protocols, etc.). The federal government also carries out surveillance practices, research, and is responsible for migration health programs, quarantines, and travel medicine. Finally, municipal governments carry out many of the same tasks as provincial governments, but rather at the community level. Municipal governments also take charge of public education and awareness, and any public health interventions, such as vaccination and screening programs, and travel health programs.

Yet, when it comes to actual policy or programs in Ontario pertaining to NERE infectious diseases attributable to climate change, the researcher was unable to find any information on such programs, let alone anything that specifically addresses malaria. That is not to say that malaria as a climate-related public health threat does not appear anywhere within government literature on the health impacts of climate change. Malaria is, after all, already on the list of notifiable infectious diseases in Ontario.

At a national level, all actions proposed by federal bodies such as Health Canada are highly focused on strengthening surveillance, and on researching and identifying the health risks posed by the impacts of climate change, particularly those which affect vulnerable groups

(Health Canada, 2005). Although this may initially seem promising from a SDOH perspective, the recommended actions lead us to question the true application of the SDOH in this context. Tailored adaptive responses are a priority, and ‘preventative health measures’ proposed by Health Canada (2007) include surveillance and monitoring, public education and outreach, and medical interventions. Although ‘legislation’ also made the list, no further detail as to what type is provided. How are these priorities reflected at a municipal level, within the focus region of the GTA?

Perspectives on Malaria within the Municipal Context of Toronto

On a municipal level, the specific mention of malaria in literature on health and climate change is scarce. For example, the City of Toronto’s (2008) *Climate Change Adaptation Strategy* describes the risks posed by West Nile Virus (WNV) and Lyme disease, diseases which are already present within the area, and also mentions the potential for malaria to re-emerge in the form of sporadic outbreaks. However, proposed adaptation strategies for NERE infectious disease include the very familiar ‘public education’ on such threats, as well as interventions to prevent disease expansion. Even within non-governmental reports on climate change adaptation and health policy, recommendations on surveillance and education predominate (Pinto et al., 2009; Pollution Probe, 2002). The degree to which these recommendations align with the realities of vulnerable groups in Toronto is questionable.

From a clinical perspective, two out of three infectious disease experts asserted that the current degree of threat posed by imported malaria in the GTA is relatively low. The third expert expressed greater concern. Issues surrounding underreporting and disease management were brought up. It was also articulated that malaria was an increasing concern in terms of the

growing number of imported cases reflecting changing travel and immigration patterns. The future risk of sporadic local outbreaks within a climate change scenario, although considered possible, was not seen to outweigh the existing burden of imported cases within the GTA. In other words, with or without climate change, malaria already represents a public health concern from a medical point of view. Changing global patterns of malaria, particularly in terms of drug resistance, represented a more valid cause for alarm for all experts.

All interviewees in both groups acknowledged that certain immigrant groups were particularly susceptible to malaria while travelling abroad, especially those returning to visit friends and family in their country of origin. As discussed in Chapter 4, this susceptibility was attributed mostly to a skewed perception of malaria risk on the part of the travellers, where most are not aware that the years they have lived in Canada would have rendered them naïve in their immunity. As a result, these same groups are the least likely to seek pre-travel advice or to use anti-malarial drugs. The presence of underlying medical conditions was generally considered, in theory, to determine the level of health outcome of a malaria infection (such as the severity of an infection), but this was thought to come second after the level of immunity towards malaria. In addition, cost was identified as an additional barrier by most interviewees in both groups, as OHIP no longer covers the cost of travel clinic visits, and anti-malarial drugs prices are increasing. Therefore, those same interviewees agreed that a combination of skewed risk perceptions and financial barriers limit vulnerable immigrant groups' access to the healthcare system. Climate refugees were mentioned within both groups of interviews as presenting another potential at-risk group.

Broadly speaking, infectious disease experts were cognisant of the social justice aspect of the impacts of climate change on health. In other words, it was clearly recognized that those with

the fewest resources will also be the least capable of resisting those impacts. However, when it came to specifically addressing the disproportionate burden of imported malaria among certain vulnerable immigrant groups in the GTA, the general consensus on the best way to protect them was to improve those groups' access to the healthcare system before they travel by means of education and outreach. Ensuring that children in particular were protected was crucial considering their higher risk of severe malaria infections.

When asked about municipal prioritization of the impacts of climate change on health, local health policy experts confirmed that heat vulnerability is at the top of the agenda, rather than the risk of NERE infectious diseases. This is consistent with the list of Toronto's ongoing adaptation actions, the vast majority of which apply to 'greening' infrastructure, heat vulnerability, and flood emergencies (City of Toronto, 2011a). One public health interviewee attributed an overall lack of attention paid towards infectious disease within municipal climate change priorities to a lack of knowledge on the scope of the problem on a local scale, and that they are "still in the exploration stage." Potential collaborative work with infectious disease researchers was in the works, although again, the focus is on enhancing monitoring and surveillance. That said, the public health official stated that they would be very open to learning more about this topic. Let us first consider infectious disease surveillance as a means of prevention, before moving on to discuss targeted adaptation measures for vulnerable populations.

In theory, adequate information on health indicators should allow for the formation of effective policy or programs. However, malaria and other infectious disease surveillance data presented in the *Communicable Diseases in Toronto* report includes no socioeconomic indicators of any kind, with the exception of those for TB and HIV/AIDS which are two established 'social' infectious diseases (Toronto Public Health, 2012). In other words, only incidence by age,

sex, and month are included for malaria. On a provincial level, surveillance results on malaria are described similarly. The lack of the necessary data with regard to general disease burden among vulnerable groups (again, excluding TB and HIV) limits the development of any relevant or useful policy.

Targeted adaptation measures to suit vulnerable populations, when focused solely upon, can represent a highly reactive perspective. For example, Pinto et al. (2009) stress: “Engagement of individuals and communities is needed to ensure that messages designed to reach vulnerable groups provide the information and motivation necessary for individuals to make appropriate choices.” (p. 22). This implies that those vulnerable groups, once they have the right information, will make the necessary choices required to protect themselves from the risks of climate change impacts, or in this case, malaria. This assumption is highly skewed in terms of understanding the SDOH and the factors that create situations of susceptibility to disease.

To provide an example, suggestions made by one public health official on general infectious disease prevention included proper hand hygiene, vaccinations, and good nutrition. On malaria and vector-borne diseases specifically, education of the public was considered a good strategy (e.g. on the removal of standing water, what times of the day to avoid going outside, etc.). It is important to recognize that these are legitimate measures; however, what is really meant by ‘prevention’ within infectious disease discourse begins to come into focus. As it was defined within government literature, infectious disease prevention tends to be thought of in the most immediate terms, and with a biomedical focus. Targeted adaptation measures have succeeded in at least identifying which groups are vulnerable; however, reducing the vulnerability of certain groups from the start does not seem to be on the radar of Toronto’s health priorities, at least with respect to infectious disease or climate change. One might then wonder

what would represent truly preventative strategies when it comes to infectious disease generally, or within a climate change setting.

Preventative policy recommendations might include those that target income insecurity and employment challenges felt by immigrant and visible minority groups, such as improving the recognition of foreign credentials, enforcing employment standards to protect workers from unsafe or discriminatory work environments, and increasing funding for things such as affordable housing and childcare (Toronto Public Health, 2011). Ideally, these changes would then be synchronized with those directly related to improving access to health care, such as expanding health insurance coverage for low-income families to include travel clinic visits and anti-malarial drugs. Yet, such policy recommendations do not appear to be gaining a foothold: what is preventing them from doing so? How much does this relate to the presence of the SDOH model within municipal health policy and the research that informs it?

5.6 Barriers to Change

Gaps between Infectious Disease Research and Health Policy

In order to gauge the prominence of the SDOH within the field of infectious diseases in a general sense, infectious disease interviewees were asked of the role of the SDOH in their own research. All asserted that social justice themes govern much of their work performed either locally or overseas. Furthermore, the link between socioeconomic conditions and disease outcomes was well understood. One individual believed that more attention should be paid to marginalized groups here in Canada, Aboriginals and First Nations in particular. All individuals emphasized that raising awareness of health disparities among particular groups was certainly within their mandate.

However, several barriers in their ability to do such work were identified, namely, limitations in terms of accessibility and the availability of certain data. As discussed in the previous section, social and economic indicators are largely missing from municipal communicable disease reports. It was suggested by one individual that even linking existing data sets together would be highly useful in identifying the socioeconomic determinants of many health outcomes, and ultimately in moving forward with the necessary policy changes. These do not represent uncommon suggestions. For example, Pollution Probe (2002) also proposed the inclusion of data on social conditions and health indicators along with those related to climate variables within monitoring and surveillance activities on climate change impacts in the Toronto-Niagara region. Improving the type and accessibility of such data has also been recommended on a national scale (Lemmen & Warren, 2004).

Regrettably, most infectious disease interviewees articulated that it was often difficult to obtain a response from decision-makers or the federal government in general, when voicing their recommendations. One individual commented: “If it’s only helping people and not saving them money, or costing them money, it gets no traction.” The need for collaboration between diverse groups that do similar work in Toronto as a means of collectively achieving a greater degree of influence on policy was also expressed by several individuals in both groups of interviewees.

When public health officials were asked to comment on the level of responsibility in pushing forward a SDOH-based agenda within infectious disease prevention or work on climate change, the two interviewees diverged somewhat in their views on the role of the SDOH in the work that they did. The public health official, whose area of expertise was on infectious disease prevention and policy, regarded it as work that was beyond their mandate. This is highly reflective of the same issue of diffusion of responsibility within the section, ‘National Climate

Change Vulnerability’, above. The other public health official who had a focus on climate change policy considered long-term recommendations which addressed the broader SDOH as essential (such as a poverty reduction strategy), but that there was a much greater need to demonstrate progress through short-term gains. This need was attributed to barriers in the political system whereby “...politicians want to see results and action, not more studies, in order to gain the support of their constituents, so for long-term things it is hard to demonstrate the progress.” Also, “...it enables you to go somewhere rather than just getting stuck, which politically, it’s hard to get support for things that don’t seem to go anywhere.” It was mentioned that contributing to this barrier are challenges in garnering public support on climate change issues, as it still remains arguable in the eyes of the public.

Considering the prominent barriers discussed here including a diffusion of responsibility on SDOH priorities, political restraints in terms of policy recommendations by public health officials, and challenges with influencing decision-making by infectious disease researchers, it becomes clearer as to why there is so little movement in terms of pushing for a SDOH-based agenda. How can we better come to understand the apparent polarity between the realm of infectious diseases and public health policy, and true applications of the SDOH? Let us now consider some of the greater forces at play which influence the role of the SDOH in terms of health outcomes generally, as a means of uncovering what this means for malaria in particular.

5.7 Politics, Economics, and the Role of Power and Influence

There are several significant ways in which our political and economic systems influence health. In a liberal welfare state such as Canada, those mechanisms that govern our society (i.e. privatization, deregulation, and trade) inherently cause a reduction in the role of the government

through the belief that state intervention and regulation will stifle economic growth (Raphael, 2011) . Therefore, a minimal governmental presence in the health sector (i.e. by assigning increased responsibility to provincial and municipal governments to deal with health issues) can have detrimental effects. As became clear through the interview process, this has also resulted in a diffusion of responsibility when it comes to not only climate change, but also in the implementation of SDOH-driven action.

From an economist's standpoint, public intervention in disease prevention is less economically beneficial than if there were none, because of the potential for private incentives (Philipson, 1999). This brings into focus the influence of profit in the field of health. Many corporations profit from poor health; for example, the argument exists that pharmaceutical companies neglect to invest in research into antibiotics and vaccines to make them more affordable because there is a much greater incentive for profit in the area of lifestyle medications and chronic health conditions (Thompson, 2011). A similar concern has been expressed for the lack of funding available to pharmaceutical companies to research and develop antibiotics to keep up with drug resistance (ISDA, 2004). In the case of malaria and increasing global drug resistance, this could not be more pertinent. Furthermore, although the role of profit may not extend into government decision-making on issues pertaining to public health, economic viability likely does. This rings true with the comment made by one infectious disease expert on the lack of traction of non-cost-effective recommendations.

Liberal welfare states are also associated with high levels of income inequality when compared to social democratic, or even conservative regimes (Coburn, 2010). This not only manifests itself within population health in the form of health inequities, but also presents challenges to achieving health equity goals from a policy perspective. There is evidence to

suggest that the social policies of the province of Ontario are highly representative of Canada's own commitments and priorities as a liberal welfare state (Bernard & St. Arnaud, 2004). This cannot be better demonstrated by the fact that income inequality is on the rise within Toronto, an indication that health disparities will follow suit. The immediate effects of growing poverty may be that certain groups face greater difficulties in accessing the necessary pre-travel advice or anti-malarial drugs. In turn, this has the potential to result in a higher incidence of infections or overall worse health outcomes.

When identifying those vulnerable groups in our province, one must also consider their level of participation in society and their corresponding level of power and influence. In the GTA, those groups most susceptible to malaria do not represent voices of power in our current society for a multitude of reasons including language and cultural barriers, social stigmatization, diminished social cohesion, or even due to a simple lack of social or economic resources hindering their ability to participate in decision-making (e.g. through a lack of education, time and energy, etc.). This is particularly true for recent immigrants who have not yet become established within society, and therefore may be less likely to participate within this process. Thus, more dominant groups are able to better exert control and make their needs heard over those other disadvantaged groups. As Coburn (2010) describes, whether or not a proposed policy change is revolutionary, if those groups behind it do not yield enough power and influence, those changes will never come to fruition. An excellent example of this is when the City of Toronto held a public forum in 2011 to encourage feedback on the city's *Climate Change Adaptation Strategy*. It was noted that those members of the public who showed up and participated exhibited an overall high degree of environmental awareness, and were thus a skewed representation of Toronto's population as a whole (City of Toronto, 2011b). Furthermore, and

perhaps not surprisingly, none of the ideas and suggestions put forward by these members of the public revolved around disease prevention, but rather on green technology and education of the public on environmental matters.

Finally, the comparison of malaria to a social infectious disease such as TB is useful in the sense that we may continue to build on the idea that malaria may also display ‘social’ characteristics. As discussed in the previous chapter, TB is a disease whose burden falls predominantly upon the shoulders of immigrant groups in Toronto (Khan et al., 2011; Zaidi, 2014). Unfortunately, a focus on screening and surveillance within Canadian TB control policies is also reinforced through the media, which disregards the role of social inequalities (poverty, malnutrition, other diseases) in reactivating latent TB infections (Reitmanova & Gustafson, 2012). This means that not only are efforts to bring the SDOH to the surface within health policy and perception of the public impaired, but the issue of high incidence of TB among immigrants becomes racialized in that the idea of TB as “a disease that resides in the materiality of the immigrant body” is reinforced (Reitmanova & Gustafson, 2012, p. 917).

The similarities between TB and malaria may be compared on two fronts. First of all, a strong adherence to the biomedical model of health with respect to TB prevention and control in Toronto also resonates within perspectives on malaria prevention and control, for example, the strong focus on surveillance and monitoring. This has the potential to mask the importance of socioeconomic determinants of malaria incidence within the GTA, thereby further reducing the power of those most affected. Secondly, the demographics of malaria and TB incidence in Toronto are very similar in that, to date, both diseases disproportionately affect immigrants. As these health demographics have contributed to the racialization of TB, they may also eventually implicate themselves within perceptions of malaria and its victims. Should the issue of malaria

risk in the GTA become more prominent within future climate change scenarios, the process of the racialization of malaria has the potential to be amplified. This may exacerbate issues of racialization already directed towards immigrant and visible minority groups in the GTA, further marginalizing them.

5.8 Conclusion

The SDOH model helps to explain changing health demographics and public health concerns in a growing city or region, and also helps to evaluate current discourses (in terms of the extent to which they are preventative vs. reactive) on diseases within municipal, provincial/territorial and federal policies and programs. Although national policy and programs pertaining to the impacts of climate change on human health in Canada are still in the early stages of development, it is still possible to identify a disconnect between rhetoric and proposed action with respect to the SDOH. Re-emergent malaria as a potential impact of climate change is touched upon only briefly in policy documents. As with infectious diseases in general, recommendations on prevention are strongly based on reactive measures such as surveillance, monitoring, and education of the public.

On a municipal level within infectious disease and health policy discourses, these priorities are similarly reflected, and malaria is not yet prioritized among the list of potential impacts of climate change on health. According to interviewees in the field of infectious disease, factors such as global drug resistance may be more compelling than climatic factors in determining health outcomes. A lack of evidence on the link between malaria and climate change within municipal decision-making is also contributory. Regardless, the disproportionate burden

of imported malaria among vulnerable immigrant groups in the GTA is already strongly recognized, as is its potential to worsen as a result of immigration and travel trends.

Improving these groups' access to the healthcare system along with eliminating financial barriers are both concerns from infectious disease experts' perspective. These priorities would undoubtedly be useful in the immediate sense; however, they are not truly preventative as this paper maintains, and are characteristic of a biomedical focus on this issue. Although the SDOH are perceived to play a prominent role within such research, recommendations such as helping certain groups achieve greater access to the healthcare system downplay the root causes of this unequal access.

A good place to start may be improving data collection to incorporate socioeconomic factors to produce the necessary evidence to facilitate the creation of useful infectious disease policy in the interest of health equity. This represents a much more preventative strategy that also sits well within the mandate of infectious disease research. Unfortunately, researchers feel they lack the ability to reach decision-makers through this process. Furthermore, the SDOH are generally considered to be outside the mandate of municipal public health officials working on health policy relating to infectious diseases within Toronto. Although this may not be the case for municipal climate change policy, there are still political barriers preventing SDOH agendas from being pushed through. Therefore, whatever the reason, it becomes increasingly clear that the SDOH lack presence within both infectious disease and climate change/health policy realms.

Finally, the broad political and economic system in which we live, work, and play is also a limiting factor in our ability to move forward with positive policy with respect to disenfranchised groups in our society and the health burden they bear. This will also certainly be reflected in our nation's capacity to receive the impacts of climate change. Locally, as income

inequality grows, health outcomes may follow suit. It is difficult to speculate whether our priorities and resource commitments are likely to change in favour of health equity, as is the manner in which malaria as a health risk will be implicated within the GTA. However, there is real potential for it to become a self-perpetuating problem as it becomes increasingly recognized as an issue of immigrants, further exacerbating stigmatization, in turn creating more vulnerability within these groups.

The next chapter will examine historical malaria in southern Ontario during the 18th and 19th centuries, perceptions regarding vulnerable groups within that setting, and what lessons we may possibly learn from this important time in Canada's medical history.

Chapter 6

Historical Malaria in Ontario

6.1 Introduction

The presence of malaria in Ontario and Canada during the 18th and 19th centuries is a history that often goes untold. The fact that this disease was at one time endemic in many parts of Ontario, Quebec, and even the Maritimes, often comes as a surprise. This may in part be attributed to the common association of malaria as tropical disease; therefore, the idea that it existed to the point of endemicity within our northern climate seems almost impossible. Examining this part of history will not only be illuminating in and of itself, but will hopefully reveal more about the impact such a disease might have in the present day or the near future.

This chapter will begin by exploring the details of who were the victims of malaria, which areas of Ontario were affected, over what period of time malaria was prevalent, what type of malaria it was, and what were the factors conducive to its presence and impact. Several broader questions will also surface; specifically, ‘how was the disease depicted?’, ‘who were the prominent voices on this topic and how might this have influenced the manner in which malaria was depicted?’ and ‘what was the social, political, and economic context at the time?’

As we turn to the past to seek instruction for problems we face today, it is vital that all biases be acknowledged, both in the sources and materials drawn upon within this research as well as potential biases in the analysis of those materials. This is to maintain accountability throughout this investigative process. Only then can we justifiably move forward in attempting to draw parallels between the past, present, and future. Finally, it is important to consider what we

can learn from the long history malaria has had with our society in this province, particularly with regard to the presence of vulnerable groups, as defined by the social determinants of health (SDOH) model. Applying this framework to the past may reveal useful parallels for informing certain groups within the Greater Toronto Area of the potential threat of malaria in the near future, but may also lend weight to the SDOH model itself through demonstrating its ability to be implicated within both current and historical realities.

6.2 A Brief History

Timeline

It is important to begin this history by emphasizing that, although malaria was at one time endemic (i.e. prevalent to a particular region or locale) in Canada, it did not originate here. Rather, malaria is said to have arrived in the Americas as early as the 1500s by means of the early expeditions of Columbus (Guerra, 1993). Slaves from Africa were also a source of malaria during the 16th and 17th centuries (Zucker, 1996). However, its arrival in Canada is presumed to have been by infected loyalists fleeing northward after the American War of Independence in the early 1780s (Fallis, 1984). Malaria was endemic in many parts of America at this time, following patterns of migration (Zucker, 1996).

It was in the early 1800s that malaria had the greatest impact in Canada. Within the region of present-day Toronto (then York, capital of Upper Canada) there were problems with malaria, defined primarily by the city's proximity to the marshland at the mouth of the Don River (White, 1958). In its 'early days' (i.e. circa 1815), the population of York was concentrated between present-day Jarvis Street and Parliament Street, and south of Queen Street (Firth, 1966). The city was described as being "...in constant struggle with malaria disease" but eventually,

“[...] as if by hygienic instinct began to move away from the fetid Don banks to the north and west.” (Mulvany, 1884, p. 246). It was not known at the time that malaria was carried by the mosquito vector which breeds in swamps and standing water, but these areas were considered unhealthy.

The construction of the Rideau Canal is possibly one of the most well-known examples of rampant malaria outbreaks. From 1826-1832, infection rates were so high during the summer months that the entire construction process was stalled (MacTaggart, 1829; O’Rourke, 1959; Wylie, 1983; Watson, 2006; Watson, 2013). By this point, malaria had become endemic along the northern shore of Lake Ontario, from Kingston all the way to Hamilton, along the northern shore of Lake Erie, as well as in the region of Lake St. Clair (O’Rourke, 1959).

Political change was stirring with the joining together of Upper and Lower Canada to form the Province of Canada, after several decades of significant political turmoil (Bone, 2013). This period also represented a time of significant government-sponsored immigration which targeted Great Britain’s unemployed farmers and craftsmen who were left without work due to the rise of industrialization. By the 1830s, 193,000 immigrants had arrived from Ireland, Great Britain, and Europe (Bone, 2013). Malaria was endemic in many parts of England and Europe at this time (MacArthur, 1946; Bruce-Chwatt & de Zulueta, 1980). It is also believed that there were outbreaks of malaria in Ireland during the 17th century (Corless, 2013), and possibly even up until the mid-1800s (Mount, 2012). Therefore, it is considered likely that some of the immigrants to Canada brought in to work the land for the sake of colony growth and development were bringing malaria with them (Fallis, 1984).

The mid-1800s saw malaria reach its peak after which it began to steadily decline (O’Rourke, 1959; Fallis, 1984). Another major influx of immigrants, this time victims of the

Great Famine in Ireland, were mostly labourers and farmers (Bone, 2013). It is around this same time that last major outbreaks of malaria occurred in the region of Cork in Ireland (during the 1840s, 50s, and 60s) (Mount, 2012). Presumably, some of these immigrants were carriers.

The 1850s and 60s saw significant growth and development in the city of Toronto and elsewhere, and new roads and railways were etching their way across the province (Bone, 2013). By 1870, the population of Ontario had reached 1.6 million, with 80% of people living in rural areas. This was changing, however, as urbanization and industrialization drew people into city centres, with infrastructure rushing to match the changing demographics (Bone, 2013). Around this time, malaria was said to have been limited to the western and northern shores of Lake Ontario, but there were, on occasion, areas that saw a resurgence, for example the locality of Chatham Kent in 1883 (Bray, 1884; Fallis, 1984). In 1882, the ‘Malarial Districts’ were defined as those counties from Chatham-Kent to Welland, i.e. those counties which make up the most southern-west portion of Ontario bordering Lake Eerie (Provincial Board of Health of Ontario, 1884). Despite some ebbs and flows, by the turn of the century, malaria appeared to be a problem of the past (Fallis, 1984).

Eradication of Malaria

It was not until well after the incidence of malaria began to decline that it was discovered in 1897 that it is transmitted by mosquitos. Initially it was believed that malaria was simply caused by noxious swamp gases; the name ‘malaria’ is derived from the Italian *mal’ aria* or bad air. Since the disease was thought to emanate from the land itself, it appears the idea of malaria as a foreign import was not considered despite its notable presence on other continents (MacKinnon, 1873; Bray, 1884). Transmission of malarial ‘germs’ were thought to be facilitated

by the decomposition of vegetative matter through combined heat and moisture, whereby these ‘germs’ would be carried up on currents of warm air during the day, and fall back down to earth in the cool evening (Bray, 1884). This was an attempt to explain why individuals who were ‘out and about’ during the evening, a time when mosquitoes are most active, appeared more likely to get infected. It was also believed that the concentration of malaria determined its virulence: “[...] in small quantities it produces intermittents, in a more concentrated form remittents, diarrhoea, dysentery.” (Bray, 1884, p. 307) and “[...] as water got scarce, the Malaria became more concentrated, and as a consequence more poisonous.” (Bray, 1884, p. 306).

Despite these misconceptions regarding the disease and its mode of transmission, endemic malaria in Ontario, and Canada in general, was in significant decline by the mid-1800s. The considerable influx of immigrants during this period from malaria-endemic regions suggests that this decline could not be attributable to a decrease in imported malaria. Rather, development is considered to be the primary factor responsible (O’Rourke, 1959; Wylie, 1983; Watson, 2013). That is not to say that there were no prior attempts to rid the area of malaria. Clear, albeit uninformed, efforts were indeed carried out. For example, Colonel By, in charge of the military-run construction of the Rideau Canal, ordered that trees be chopped down in rows for the purpose of improving air circulation adjacent to the canal, although this had no positive effect (Wylie, 1983). Also, as previously mentioned, swamps were considered unhealthy, and draining them was long seen as an effective technique for reducing the incidence of malaria, even though it was not fully understood why (Bray, 1884). York’s growth away from the ‘fetid’ Don banks underlines the preference for housing further away from these unhealthy locations.

With development of the area came significant land use changes, primarily the draining of swamps for the purposes of agriculture as well as for human habitation (O’Rourke, 1959;

Watson, 2013). Population growth led to inevitable socioeconomic development, accompanying the advancement of agricultural and urban landscapes, and there was a steady improvement in hygienic conditions (Mulvany, 1884; Fallis, 1984). Along with this came the use of glass and then screen in windows and doors (Watson, 2013). Quinine was known to be effective at mitigating the symptoms of malaria; however, during the first few decades of the 19th century it was “[...] very dear, poor people at a loss to procure it.” (MacTaggart, 1829, p.18). It was only in later decades that its use became extensive, ultimately contributing (although not significantly) to the eradication of malaria by the turn of the century (Fallis, 1984; Watson, 2013).

Ultimately, the change in proximity of human habitation to mosquito breeding grounds, be it through moving further away or altering the landscape altogether through development, appears to have been the determining factor in the ultimate eradication of endemic malaria in this area. It has been suggested that the disease reached its critical level before any conscious or deliberate steps were taken toward antilarval action (O’Rourke, 1959). However, it should be noted in conclusion that although techniques such as draining swamps to reduce malaria may not have been entirely understood, they were nevertheless effective. Bray (1884) on the transformation of marshes into farmland:

[...] and when this has been accomplished one great source of Malaria will have been removed, and the public health materially benefited. I think that no government could employ the funds at its disposal to better purpose than the improvement of the country and the health of its inhabitants. (p. 306)

Also mentioned in the same Provincial Board of Health Report (Provincial Board of Health of Ontario, 1884, p. xxiii) is the following statement: “The experience of Great Britain and other countries goes to show that thorough drainage helps greatly to free such districts from Malaria.”

These statements indicate that it was known that the transformation of marshland into agricultural land was beneficial in terms of reducing malaria; as such, these might very well be considered to have been conscious or deliberate efforts after all.

Which Type was It?

Malaria was a disease of many names including malarial fever, ague, chill fever, ‘the shakes’, and intermittent fever (MacKinnon, 1873). But, as the evidence suggests, one species of malaria, *Plasmodium vivax*, most likely dominated at least southern Ontario throughout much of the 19th century, although there is some evidence that *Plasmodium falciparum* may have also made an appearance. The two forms differ primarily in their virulence. *P. vivax* has a very low mortality rate despite a high morbidity rate (Watson, 2013). This means that although many individuals may become infected with this type of malaria, it is not at all common for them to die from it. As discussed in Chapter 2, *P. falciparum* is the most dangerous of the four types of malaria associated with humans, invading many more red blood cells than its temperate cousin; as such, it is more likely to result in severe infections and death if gone untreated (Centre for Disease Control, 2012). Another distinguishing characteristic is that *P. vivax* has the ability to go dormant within the human liver for months or even years before it reappears, known as a relapse (CDC, 2012). *P. falciparum* does not have this ability. This means that *P. vivax* would have had the ability to overwinter in Canada (hibernating within its human host), whereas *P. falciparum* would have had to be reintroduced every summer.

Different regions may very well have seen different forms of malaria depending on who imported them from where. For much of southern Ontario at least, there are numerous signs that indicate the prevalence of *P. vivax*. In the region of the Rideau Canal, MacTaggart, clerk for Lt.

Colonel John By (1829, p. 18) makes several revealing statements regarding ‘Fever & Ague’: “This is the most prevalent disorder: sometimes it proves fatal, but not generally so by any means.”, and “Those who have it once, will most likely have a touch of it every year.” Bray (1884, p. 307), points out that certain individuals “[...] have a continued supply in their systems [...]” and MacKinnon (1873, p.1) states: “[...] malarial fever may be seen and studied in all its forms, except the most malignant, which is rarely met with on the Canadian side.” These excerpts correspond with the two distinguishing features of *P. vivax*: its low mortality rate and reoccurring nature.

Based on surviving death records for workers on the Rideau construction, the mortality rate associated with malaria was somewhere between 2-4%, a rate considered abnormally high for *P. vivax* (Watson, 2013). Through extrapolations, it was estimated that approximately 500 lives were lost to malaria, including women and children, at least during the primary years of construction (1827-1831) (Watson, 2006). The majority of deaths would have occurred between August and mid-September.

There may be various possibilities to explain the abnormally high death rate associated with malaria at this time. Extrapolations from the same surviving records used to document malarial deaths from 1827-1831, indicate that around 500 people died from dysentery, small pox, and work-related accidents (Watson, 2006). Since half of all deaths were attributed to malaria, and the other half to other diseases, it is highly probable that many of these individuals were in fact suffering from multiple infections. This is exceedingly likely considering the poor living and working conditions that comprised the Rideau construction (more on this topic will follow).

Another possibility is that there was indeed *P. falciparum* present, only to a much lesser extent than *P. vivax*. It would have had to have been to a lesser extent otherwise higher mortality

rates might have been observed. MacTaggart (1829, p. 18) alludes to this by referring to another form of malaria directly after describing the ‘Fever & Ague’ (see above), as if distinguishing between the two: “The Lake Fever prevails at Kingston, York, and other towns and villages on the borders of the great lakes. It is often fatal, and the nature of it as yet seems not well understood [...]” It is possible that he is describing another, more dangerous, type of malaria (*P. falciparum*).

6.3 Facilitating Factors

Geography

There is no doubt that the incidence of malaria was highest in the vicinity of marshland and rivers, particularly in the case of the Rideau Canal where men, women, and children were living and working right alongside prime mosquito breeding grounds. MacTaggart (1829, p. 5) goes into great detail about the logistical challenges of construction presented by the marshland in the area, there being “no possibility of avoiding it.” ‘Cranberry Marsh and Sickness’ is another central topic; MacTaggart (1829) devotes a full chapter to this in his book, *Three Years in Canada*. Lord Selkirk also spoke of Toronto in its early days: “This situation is found to be unhealthy from the neighbourhood of a marsh of 1000 acres formed by the mouth of the Don.” (White, 1958, p. 143). MacKinnon (1873, p. 1) also makes the ominous association between malaria and landscape: “It even seeks by preference the fertile river valley, with its abundant foliage and fields; it follows man to the hill-sides, and finds him out on the mountain tops and slays him there.”

It is considered likely that the species of mosquito vector at the time was *Anopheles quadrimaculatus* (O’Rourke, 1959). This species is still considered today the dominant mosquito

in Ontario and Quebec as well as the dominant competent vector for current cases of *P. falciparum* and *P. vivax* in the eastern USA (Berrang-Ford et al., 2009). Those living in proximity to swamps and rivers would have been most affected, but since mosquitoes also breed in standing water, permanent or ephemeral, their distribution would be fairly widespread (as is still the case today) within the limitations of its temperature requirements. However, as development of the region advanced, swamps were drained, ravines filled and streets built, and much of the vector's habitat was destroyed.

Weather and Climate

Climate was a strong determinant of the ferocity of a malaria season, this connection being made very early on: "A moist, hot summer fosters it very much; and when we fairly take it, we are rendered useless for any active business for many months." (MacTaggart, 1829, p.18). In fact, the years 1829-1830 saw particularly hot, muggy late summers such that a considerable amount of construction was halted for the 'sickly' months of August and September in southern portions of the canal (Wylie, 1983). MacTaggart (1829) also noted that when long periods of continued hot weather occurred, the 'vitality' of the disease was diminished. However, a wet spring followed by an exceptionally hot and dry summer and autumn in 1881 produced "the most unhealthy [year] I ever knew in this county and the mortality the highest ever experienced" (Bray, 1884, p. 307). This was compared to years where more rain kept the low lands submerged and where malaria was much reduced. Bray (1884) also noticed an overall difference between the generally wetter month of May and the drier month of October, with malaria incidence being higher in the former.

Interpreting these climatic conditions in terms of their favourability towards the prevalence of malaria involves a consideration of breeding preferences of its likely vector, *An. quadrimaculatus*, as well as the temperature requirements of the *Plasmodium* parasite itself. As discussed in Chapter 2, *Anopheles* mosquitoes require standing water in order to reproduce and lay their eggs as well as direct sunlight which speeds the development process of larval stages due to the resulting increase in water temperature (Ovadjie & Nriagu, 2011). However, above or below a certain temperature threshold, or with too few days at the right temperature, the stages will not develop. Temperature thresholds and minimum required development periods also exist for the *Plasmodium* to fully develop within its vector host. Therefore, a sufficient amount of standing water (i.e. high rainfall) combined with high sustained temperatures represents ideal conditions, as long as the temperature thresholds are not surpassed for the sake of mosquito stages and pathogen development, as well as for water availability. These conditions are consistent with those periods described in the historical records above when malaria was particularly prevalent.

Living and Working Conditions

The majority of immigrants who came to Upper Canada (Ontario) during the beginning of the 19th century were seeking employment and, for the most part, arrived from England, Scotland, and Ireland with few economic resources (Wylie, 1983). With the construction of the Rideau and other canals, and general development of the land on-going, employment did exist. However, labour demands exceeded supply, forcing immigrants to accept work despite exceedingly poor working conditions, low wages, and high job insecurity (Wylie, 1983; Watson, 2006). Those conditions were comprised of 14-16 hour days of almost entirely manual labour

with one day of rest a week. The wages barely covered the high cost of living in the labour camps which, at least, included basic food essentials, but for the working men only, not for their families (Wylie, 1983). However, what little earnings were left were often hardly enough to provide labourers' families with decent food and shelter. As such, women and children could either bunk with the men in crowded work shanties, or families could construct their own accommodations – usually in the form of mud huts – which were equally crowded and unsanitary (Wylie, 1983). Crowding, abysmal ventilation and sanitation, poor nutrition of women and children, along with a likely high stress environment for all provided ideal conditions not only for rampant malaria outbreaks but for other infectious diseases as well. These conditions would also have compromised the general health of all individuals, putting them at greater risk of co-infections, more severe infections, and death. For all of these reasons, the general health of the population was likely quite poor.

General Health

Interactions between the immune system and malaria, particularly under the poor conditions of the time, would have been complex. Immigrants (who comprised about half of the workforce on the Rideau, the rest being French Canadians) would have arrived in a deteriorated state of health after the long voyage across the Atlantic (Wylie, 1983). As described above, the typically heavy workload and less than ideal living conditions of a common labourer of that time would have taken their toll, making men and their families vulnerable to other illnesses.

As previously mentioned, dysentery and small pox were leading causes of death, along with work-related accidents (Watson, 2006). Tuberculosis (TB) or 'consumption' was also common and was "of the most rapid nature too" (MacTaggart, 1829, p. 19). This implies that the

disease progressed quickly, perhaps because the immune system of TB patients was already compromised to some degree. This can also be surmised from the following statement, referring to malaria: “[...] some people have a continued supply in their systems, only waiting to develop itself when a person is exhausted by over-fatigue or loss of rest or otherwise runs (sic) down.” Bray (1884, p. 307). This statement also expresses the understanding that malaria had the ability to exist within the body without the carrier showing any symptoms, i.e. latent malaria.

In fact, it was not until the later part of the century that malaria was considered in isolation as a disease. While the term ‘ague’ was commonly used (a term that generally referred to a continued fever), malaria, typhus, and other fever-inducing ailments were all grouped together as the ‘fevers’ (MacArthur, 1949). In the latter part of the 19th century, despite its clear distinction from other diseases, malaria was nevertheless simply one in a whole range of health threats faced by the general public. For example, the Second Annual Board of Health Report of Ontario describes six groups of diseases: the fevers, the diarrhoeal diseases, diseases of the respiratory organs, eruptive diseases (including measles and small pox), consumption and other tubercular diseases, and venereal diseases (Provincial Board of Health of Ontario, 1884). This system of classification exemplifies a period that was vastly complex in terms of not only understanding disease but also experiencing them (i.e. symptom cross-over). This point is made all the more evident below where malaria is described in relation to other diseases. The combination of a vast influx of people in varying states of health, a lack of any proper health infrastructure and poor sanitation, lack of knowledge in terms of hygiene and disease prevention, and poor working and living conditions were conducive to a stressful and volatile setting that was highly favourable for disease transmission.

Indeed, by the late 1800s a profusion of other diseases abounded, as described in the same Board of Health Report (Provincial Board of Health of Ontario, 1884), the most prominent being measles, diphtheria, small pox, and typhoid. Connections were made, at the time, of the association between certain diseases or illnesses and living conditions: “[...] if we have to wander in the wilderness amongst swamps, as many have – to sleep amongst them, and be obliged to drink bad water – the *Dysentery, Fever and Ague* and all manner of bilious fevers, are sure to succeed one another.” (MacTaggart, 1829, p. 16). This connection is made with specific reference to malaria as well: “[Malaria] leaves, however, dregs of various kinds behind it, which often end in dropsies, consumption, &c.” (MacTaggart, 1829, p. 16). Dropsies were another name for edemas which are defined as the accumulation of excess fluid within the circulatory system or within tissues; it is indicative of an underlying health concern such as heart failure, kidney or liver disease, malnutrition, etc. (Edema, n. d.).

It has been suggested that those who died from malaria, as described in the surviving reports from the Rideau, were most likely already suffering from other illnesses and that malaria was simply the final stroke (Watson, 2006). For example, conclusions of the role of malaria on the immune system are strongly and eloquently stated:

Its power, however, to induce other diseases is beyond the province of speculation. By its property of lowering the vital powers, it leaves the body the prey of other diseases. I am satisfied it, in this way, excites the tuberculous diathesis and assists that disease to overcome its victim. That it is conducive to neuralgic and rheumatic affections, is also certain. It renders epidemics, such as cholera, more fatal; and endemics, of whatever kind, are intensified by it. Scarlatina and diphtheria are especially fatal in malarial districts. (MacKinnon, 1884, p. 4)

Clearly, MacKinnon is describing the immune system when he refers to the body's 'vital powers'.

Whether it was the malaria that was the last straw or some other ailment, it is impossible to say. However, the point is that many individuals were suffering from generally poor health for a number of reasons, creating a population that was not only vulnerable to acquiring an infection, but vulnerable in succumbing to that infection. The ability to recover from malaria is extremely pertinent as well, as it would have significantly affected the likelihood of returning to work. Many labourers on the Rideau were indeed driven away for this very reason (Wylie, 1983).

6.4 Victims of Malaria

There appears to be a clear distinction between two groups of sources on the matter of who exactly were the victims of malaria throughout the 19th century. One group describes 'victims' as those who became infected with malaria (including those who recovered), whereas the other describes them as those who suffered the most from malaria (vs. those who were able to recover). This difference is important because the latter is indicative of underlying health problems and the conditions that result in that vulnerable state.

For example, Watson (2013) describes malaria as having infected 'indiscriminately', striking down even high-ranking officers and their families with fever. Quotes from records at the time back this up: "doctors and all were laid down together." (MacTaggart, 1829, p. 21); "[...] Malaria in that region is a question of prime importance, affecting, as it does, the well-being of a large population.", referring to valley of Grand River in southwestern Ontario (Provincial Board of Health of Ontario, 1884, p. xxii); and "[...] Malaria is (sic) some form or other took possession of nearly every house when this state of things prevailed..." (Bray, 1884, p.

306). These quotes illustrate who became infected with malaria (i.e. practically everybody), but do not tell us anything about who suffered the worst, such as from more severe infections.

Since those few surviving records from regions such as the Rideau Canal distinguish only between men, women, and children and give no other information as a means to differentiate the victims, it is difficult to know for certain exactly who they were, at least in this area at this time. Certain clues are provided, however. Referring specifically to Irish immigrants, MacTaggart (1829, p. 244) speaks to their vulnerability: “They absolutely die by the dozen, not of hunger, but of disease.” In the later part of the century, Bray (1884, p. 305) also refers to ‘exceptional cases’ of malaria among immigrants compared to those ‘old residents’ who may have become acclimatized.

Wylie (1983, p. 19) appropriately suggests that it was very likely the “common labourer and the destitute immigrant, who were often the same person” who saw the most severe health effects from malaria as dictated by their compromised immune function from poor living and working conditions. These people are compared to those individuals who may have experienced a higher quality of life, such as the artisan, manager, or even the French Canadian labourer, being perhaps more established in the region.

From this, one might presume that it was the fact that recent immigrants arrived in Upper Canada with no immunity to malaria that may have put them at a particularly high risk of severe infection. Recall that malaria was endemic in Britain during the 19th century as well, a period that represented a particularly bad time for malaria in both nations (Kuhn et al., 2003). This may have allowed for some immunity among English immigrants; however, the same cannot be said for the Irish and Scottish.

The history of the impact of malaria on Aboriginals is somewhat contradictory. Whereas MacTaggart (1829, p. 18) vehemently asserts that “The Indians are never troubled with any thing of the sort”, others believe that there was a spread of infection to the native populations in Ontario (Fallis, 1984). In the Provincial Board of Health Report for 1882/1883, the mention of the presence of malaria among Aboriginal populations is as follows:

Among the Indians of the Reserve the disease, as shown by the reports of Dr. Dee from Tuscacora [now Six Nations Reserve, Brant County], Government Physician to the Indians, prevails to a degree which is simply enormous; and certainly it cannot be said that the Reserve land is of a low-lying or marshy character. (Provincial Board of Health of Ontario, 1884, p. xxiii).

This implies that, despite the region not being conducive to infection (as defined by marshy, low-lying areas), malaria is nevertheless prevalent. It was posited that since ‘Indians’ would always go to their physician to request quinine, whereas non-natives would often procure it themselves, the records would give the impression that this district had a particularly high prevalence of malaria (Provincial Board of Health of Ontario, 1884).

Finally, MacKinnon (1873) makes several clear distinctions among individuals and their capacity to bear the burden of malaria, without ever generalizing in terms of nationality, origin, or any particular classification of that kind. It was observed that one individual would get sick from malaria whereas another did not, despite both living within the same malarial district. MacKinnon (1873, p. 3) attributes this discrepancy to the role of a “lowering of vital powers” whereby some individuals may be habitually sick from other ailments, exhaustion, etc. Furthermore, the duration of symptomatic malaria was said to vary depending on the ‘constitution’ of that infected person as well as where they reside, noting that “It sticks to certain

persons with wonderful tenacity.” (MacKinnon, 1873, p. 4). Similar conclusions are proposed with regard to malaria in England: “The disease is rarely fatal (under favourable circumstances). The chief mortality is amongst indigent and debilitated persons and their families, who have fallen an easy prey to diseases of a general character in consequence of their reduced condition.” (MacArthur, 1949, p. 1).

To conclude, the poorer, working class population who also were also often immigrants most likely suffered the most from malaria (physically as well as financially), whereas the wealthier, more established individuals fared much better in terms of recovery from infection as well as in terms of recurrence of infection. Although this might seem intuitive, it is important to make the distinction between those with generally poorer health and those with better health with the aim of establishing the social and environmental determinants of the time. It also helps to understand the varying role a disease such as malaria would have on different individuals.

6.5 Prominent Voices

It is relevant now to explore the motivations of those individuals who represent the sources most commonly featured here in order to understand how these perspectives may have influenced the material they produced. Note that there are no first-hand accounts represented here from those considered ‘commoners’, such as the labourer and/or immigrant.

G. J. Bray was a medical doctor in Chatham, Kent as well as the Ex-President of the Ontario Medical Council, and worked in the ‘malarial district’ of Kent for over two decades (Bray, 1884). A. MacKinnon was a general practitioner in Sarnia who also wrote for the *Canada Lancet*, the medical journal of the time, on the topic of his experiences with malarial patients. MacKinnon represents a respected voice on this topic.

The ‘modern’ doctor of the 19th century, despite being generally unable to provide very effective treatment due to the limitations of medical science of that time, was very good at history-taking (recording the medical history), observation (examination of the body), and differential diagnosis (identifying the signs and symptoms of a disease) of their patient (Shorter, 1991). This highly patient-oriented technique would have instilled some degree of confidence in the malarial patient, but not necessarily more so in the malarial patient than in any other. Malaria was but one of many infectious diseases posing a threat at that time, and since effective treatment (quinine) was not readily available to most until the latter part of the century, the doctor would not have been able to offer much assistance to those who could not afford it during the period where malaria was most rampant (prior to 1850).

Furthermore, malaria was still not fully distinguished from other diseases even in the 1880s. For example, the Provincial Board of Health Report provides statistics on ‘Intermittent’ and ‘Typho-Malarial’ fevers. The term ‘typho-malarial’ was used loosely to describe co-infections of typhoid and malaria in the late 19th and early 20th century; however, the actual number of documented cases is considerably low of which over half were incidents where the patient contracted malaria while recovering from a typhoid infection (Smith, 1982). Malaria would have been grouped in with other fever-inducing illnesses; as such, the public’s perception of malaria specifically is difficult to define. That said, there is clear evidence of a mistrust of doctors at least during the earlier part of the 19th century, as suggested by MacTaggart (1829, p. 20):

The country swarms with quacks, and a man of real surgical merit receives no encouragement; people are apt to prescribe for themselves when they take a turn of illness, and so are hurried out of the world sooner than most likely they otherwise would be.

This, combined with the fact that non-native individuals would often procure their own medicine (quinine) in the later part of the 19th century indicates that the role of the doctor was not necessarily essential in the eyes of the malarial patient, and could be easily bypassed.

Returning to the idea of the focus on the patient by the physician, it is worth elaborating on the considerable attention given to the body's defence system. Although not yet properly understood, the concept of the immune system was considered highly relevant.

Dr. MacKinnon (1873, p. 3-4) described his encounter with a patient suffering from malaria, whose wife and son also came down with the disease, and theorized:

[...] the woman carried in her system a certain amount of malaria, as everyone residing in a malarial district does; in nursing her husband she inhaled an additional portion, sufficient to overcome her resisting force. That lowering of the vital powers, from any cause, affords the poison an opportunity for asserting its ascendancy over the system, I readily admit.

The point that is not made, and may have been outside of his role and mandate as a GP, was to make any kind of assertion in terms of the type of person who was most likely to see the greatest consequences from a malarial infection.

Individuals such as MacTaggart, civil engineer and clerk for Colonel By, would have had no such restrictions in developing theories based on his own observations. Being a malaria survivor himself, his description of the symptoms he felt while ill are entirely valid. However, he does not hold back in making claims regarding the Irish immigrants specifically:

In summer, again, the intolerable heat, and the disregard they pay to their health, by living as they do, and drinking [swamp waters], if there be none nearer their habitations, instead of spring or river water, bring on malignant fevers of all kinds. (MacTaggart, 1829, p. 244)

The connection implied here is that unsanitary habits are the cause of suffering greatly from malaria, and this particular group of immigrants is targeted.

6.6 What Can We Learn from History?

First and foremost, as discussed in the section on “Prominent Voices”, it is essential that any biases within the source material as well as any conclusions drawn from it be accounted for. The Provincial Board of Health report referenced here does not report deaths, only cases of infection, as reported by the physicians of each health district. Such records of malarial infections, as mentioned above, are clearly biased in that they only represent those individuals who actually visited their physician. Furthermore, it was only in 1882 that the Provincial Board of Health was formed at all, along with the requisite weekly reporting of disease by district. Prior to this, it was the responsibility of the municipalities to handle public health, a task at which they apparently carried out rather poorly (Ontario Legislative Assembly, 1887). This implies that systematic health data collection was not prioritized for a better part of the period during which malaria posed the greatest concern.

The discussion on which type of malaria may have been most prevalent in Ontario throughout the century is based on accounts that are primarily qualitative. There exists an inherent bias in such accounts for obvious reasons; however, one cannot immediately discount them simply because they are not ‘hard’ data. One must remember that even hard data from that time, i.e. death records, were biased because they simply did not understand enough about malaria (and other diseases) to be able to accurately state what was ultimately responsible for a death. As such, the decided ‘cause of death’ was likely often misinformed. It is entirely possible that qualitative records are just as reliable, in this particular context, as quantitative records.

The climatic conditions conducive to particularly terrible malaria outbreaks, as described in many historical records, were consistent among themselves despite being inherently biased, i.e. hot, humid summers with long sustained periods of high temperatures. Also, in the Provincial Board of Health Report, a diagram detailing mean monthly averages of temperature, atmospheric pressure, monthly rainfall, and humidity is provided which quantitatively supports any qualitative remarks about the weather during this period.

The estimates on the number of deaths (malarial and other) during the construction of the Rideau Canal were, as previously mentioned, extrapolations, and thus are clearly limited in that sense. Furthermore, these estimates only represent the deaths that occurred among workers and their families during a certain period in a certain region. It is probable that the Rideau Canal represented one of the more severe examples of malarial outbreaks in the province, considering the high concentration of people, poor sanitation, etc. However, the exploration of this particular history does allow for some idea as to the life led, and challenges met, by the common labourer/immigrant in Ontario at this point in history. It is also important to state that the idea that common labourers/immigrants suffered most from malaria infections is only speculative, considering the lack of detailed records on victims. That said, there is strong evidence for this since we know of the poor living and working conditions experienced by the typical working-class individual as well as of the likelihood that those conditions would affect their health negatively. This, combined with the prevalence of malaria at the time, strongly supports this point.

When it comes to examining the history of malaria in Ontario, the factors are numerous, complex, and highly intertwined. However, as is evident through the discussion of the victims of malaria and the particular conditions that were conducive to their susceptibility to this disease

and others, the SDOH model is very much applicable to this particular time in history. In other words, the presence of vulnerable groups during this period provides clear support for this model in that the individuals who appeared to have suffered most from malaria were those who were most disadvantaged socially and financially. In the case of the Irish immigrants, and most likely the majority of poor working-class immigrants during the 19th century, it was not their behaviours which ultimately determined their health outcomes, but their circumstances.

Today, attempts are being made to shift away from a focus on specific behaviours as determinants of health toward understanding the circumstances that result in those behaviours. The physician's focus on the patient vs. the symptom or behaviour and the emphasis on the importance of the role of one's 'vital powers' (i.e. immune system) are examples of the manner in which the SDOH model was carried out, albeit unknowingly, during this period in history. The SDOH framework is defined by its broad and complex consideration of all determinants of health. Although it represents a relatively recent model, it is clear from this analysis that it is not only useful in current applications but in historical applications as well. We must move forward in acknowledging the saliency of this model today, and recognizing the manner in which it resonates throughout history can help.

Chapter 7

Conclusion

Malaria Today

Throughout this paper, we have navigated through many disciplines and temporal scales. Making sense of each discovery is never easy, let alone understanding how these elements may interconnect. However, the social determinants of health (SDOH) as an explanatory model and theoretical framework has consistently provided the means to link these seemingly diverse concepts involving health, climate, history, and policy, among others. The following section will re-examine the main concepts of this paper, and will make note of areas that were not able to be fully explored and which may require further study.

By first examining the question of imported malaria as it is situated within our Canadian context, we uncovered issues surrounding underreporting, identification, diagnosis, and treatment. We have demonstrated some shortcomings on the part of the public health sector in dealing with this disease. Also, inadequacies within the surveillance system were identified, possibly limiting our nation's ability to keep up with current disease trends. This topic also resurfaced within the interview process, where a paucity of socioeconomic indicators within municipal and provincial disease surveillance was identified as a barrier to beneficial policy change. Rather, global drug resistance trends, although only briefly acknowledged here in this paper, were of particular concern to infectious disease interviewees. This is an area that merits further study in order to investigate this global impact on local disease outcomes.

Next, notable at-risk groups within the GTA were identified: those who already face considerable threat of imported malaria infections, but who may also be implicated similarly within a future climate change scenario in the form of locally transmitted infections. Their degree of vulnerability is based on certain risk-factors involving population demographics and distribution within the GTA; their high association with poverty; their health burden from other infectious diseases, namely TB and HIV; and the corresponding degree of malaria risk within their source countries. These at-risk groups include African, south Asian, Filipino, and Chinese multiple-generation immigrant communities. However, African and south Asian immigrant groups were considered to be particularly vulnerable based on the high prevalence of malaria within their source regions, with African immigrant groups also facing additional challenges such as the growing issue of HIV and poverty in the GTA.

Broadly, there are many socioeconomic and health-related factors one must take into account when assessing the scope of imported malaria in the GTA. These include: current travel and immigration trends and dynamics; limitations in accessibility to the public health system by at-risk groups resulting from financial barriers, skewed risk perceptions, and possibly other unexplored factors; the disproportionate burden of poor health outcomes caused by poverty; and the strong link between racialization and poverty. According to the last Census (2006), the poverty rate for racialized individuals was 22% vs. 9% for non-racialized individuals, and 11% overall in Canada (National Council of Welfare, 2012). Since 75% of all recent immigrants belong to racialized groups, the argument that poverty among immigrants is attributable to racism is strong (McKeown et al., 2008; Raphael, 2011). The racialization of disease is an area which merits further consideration with the goal of exploring how malaria might to contribute to

the process of racialization, as well as being affected by it, particularly within the context of a highly multicultural urban setting such as the GTA.

This idea opened to the door to discussion on those broader forces which influence the layout of socioeconomic challenges. The connection between Canada as a liberal welfare state and its tendency towards income inequality could not be more relevant than in Toronto, as it particularly affects immigrant and visible minority groups. The result: a lack of power and influence held by these same groups for financial or social reasons limits their involvement in the decision-making process whereby their needs go unheard. Political barriers at the municipal level prevent broader issues, such as the role of poverty in determining health outcomes, from fully surfacing. The need for politicians to gain the support of the general public places restrictions on the changes that can take place. As mentioned in a health policy interview, the tendency is for only those policy changes characterized by short-term gains to proceed, in the name of ‘progress’. This feeds and is fed by a reactive and biomedical focus within the fields of infectious disease, public health, and climate change policy, where a skewed definition of disease ‘prevention’ dominates. Finally, a perceived disconnect by infectious disease researchers between themselves and decision-makers at various levels of government makes progress even more challenging.

It must be noted that this paper, although attempting to incorporate discourse from the broader GTA whenever possible, was undoubtedly focused on the City of Toronto due to its greater availability of information. Therefore, more work can be done to examine populations in the municipalities of Halton, Peel, York, and Durham, to see what initiatives are being carried out there, and how perceptions of imported malaria differ within these contexts. At this point, we have been able to grasp the issue of imported malaria as a current public health concern within

the GTA. Looking to the future, one can really only speculate on how this issue might manifest itself, at least with the information available. However, these considerations are still necessary as a means of understanding how this issue may evolve, and in order to implement the lessons of the precautionary principle.

Malaria Tomorrow

In order to assess future risk of local malaria transmission in the region of southern Ontario, climate projections on temperature and precipitation were examined. To briefly summarize, it is anticipated that southern Ontario will see hotter summers along with more frequent extreme rainfall events, two conditions that are expected to increase the potential for malaria transmission in this area (Berrang-Ford et al., 2009). However, this only represents theoretical transmission potential. It became increasingly clear that within the discourse on infectious disease, as determined through the interview process with infectious disease researchers/clinicians, certain other factors were more prevalent in demonstrating risk, e.g. global drug resistance, immigration trends. Considering these factors, the issue of imported malaria may already represent an underestimated public health risk, irrespective of a changing climate.

Challenges with predictive modelling and an overall lack of locally conducted studies on the link between this region's most competent malaria vector, *Anopheles quadrimaculatus*, and climate change are areas that could represent future research on this subject. This lack of evidence was identified as a barrier towards a greater recognition of malaria as a climate-sensitive disease by municipal policy-makers. Exploring the extent to which ongoing municipal disease prevention programs, such as the *West Nile Virus Prevention Program* carried out by

Toronto Public Health, may inform potential malaria prevention programs could be a good start. Another topic which could not be fully investigated within the restraints of this paper was the issue of changing migration patterns resulting from climate change, and the potential influx of climate refugees into Canada. This was mentioned by both groups of interviewees as worthy of concern, and a study on this topic could certainly contribute to our understanding of the scope of the issue of malaria.

Although a significant portion of southern Ontario's landscape has been altered since the 19th century (swamps drained, urbanization, etc.), the presence of the competent mosquito vector today is very real as is its ability to thrive. In future research, it will be necessary to explore the balance between an increase in transmission suitability due to climate change and a reduction in habitat suitability due to past (and current) development. In other words, how does the GTA environment, as an urban setting, support vector populations of *An. quadrimaculatus*, and to what extent do these areas intersect with high-risk immigrant communities? In terms of current development, the *Don Mouth Naturalization and Port Lands Flood Protection Project* is an initiative spearheaded by Toronto and Region Conservation Authority, Waterfront Toronto, and the City of Toronto which intends to naturalize the mouth of the Don River, an initiative which is hoped will also reduce flood risk. How this and other projects may influence the suitability of breeding habitat for *An. quadrimaculatus* should be examined.

Malaria Yesterday

Drawing historical parallels between malaria in the past and malaria in the present was possibly one of the most interesting components of this research. However, choosing to use environmental history as a field of research as well as a tool for methodology is fraught with

many challenges. As a researcher, one must always be aware of the biases inherent to the disciplines drawn upon, and to the sources used. Although this researcher's knowledge of the field of medicine is limited, accountability to the highest extent was maintained by continuously questioning the source materials themselves as well as the conclusions drawn from them.

Perhaps the most salient connection that could be made between historical malaria outbreaks in Ontario, current at-risk groups, as well as what may be anticipated for these groups in the future, is 'who'. Who were the individuals most affected, what lives did they lead, and how were those lives similar to today's? In the past, the immigrant arrived looking for work, was most likely poor or even destitute, and met significant challenges in terms of obtaining and maintaining employment. Men were forced to accept dangerous and low-paying work because employment demand exceeded supply. Therefore, they and their families endured abysmal living and working conditions which ultimately compromised their health and well-being. If and when they contracted malaria, the severity of the infection as well as their ability to recover would depend highly on their general state of health, lifestyle, and the presence of other diseases or infections. The degree to which malaria affected their day-to-day lives would have been, on the whole, much greater than those with a higher social status and income, as their ability to return to work after suffering from a malarial infection would be greatly compromised.

Today's situation might even be considered worse: immigrants arrive in Canada with, for the most part, the means and qualifications to flourish by any standards due to a rigorous selection process, yet somehow this is not enough to ensure them a secure living. As explored in Chapter 4, recent immigrants to Canada face an exceptionally high risk of poverty, regardless of age or education (Raphael, 2011). Recent immigrants have trouble finding full-time employment and must often settle for part-time, unstable, and low-paying work with few to no benefits

(Raphael, 2011). Unequal access to housing exacerbates the problem so that multiple families are forced to live in crowded quarters (Raphael, 2011). Even with rising education levels among Canadian immigrants, relative earnings have been falling, and, not surprisingly, poverty rates are on the rise and have been for the past 20 years (National Council of Welfare, 2012).

Although the context has changed drastically, as have the challenges faced by recent immigrants today compared with those of the 19th century, the results are the same: compromised living and working conditions result in generally poorer health and a greater susceptibility to infection. Inevitably, this further compromises living and working conditions. In the past, those infectious diseases included dysentery, TB, and small pox. Today, immigrants still account for the majority of all TB cases in Toronto, as well as a significant portion of HIV/AIDS cases (Khan et al., 2011; ACT, 2013). Local outbreaks of malaria could pose a serious threat to immigrants living in Toronto, just as they did to immigrant labourers of the past.

Concluding Thoughts

“To evaluate environmental changes as good or bad, one must first define the criteria being used: good or bad for whom or what, for which people or species and so on.” (van Dam & Verstegen, 2009, p. 26).

This quote is particularly relevant in terms of how this piece of work has made attempts to contribute to a better understanding of how disadvantaged groups in our society have dealt with disease outbreaks in the past, how they deal with disease today, and how that compares to what may be expected in the future. However, as a researcher, one must question the degree to which one is imposing one’s own values on these particular groups vs. allowing them to speak for themselves? Moreover, is one diminishing their worth simply by attempting to ‘help’ them?

At this point it is important to acknowledge that this research has been hypocritical in the manner in which particular vulnerable groups in the GTA were recognized. For instance, these groups were identified as lacking the voice to make their needs heard; however, at the same time, the only interviews conducted were with individuals who represented characteristic voices of power and influence, i.e. scientific researchers and policy-makers. Therefore, taking this research to the next level would entail speaking to individuals who belong to these identified at-risk groups in order to fully involve them in this research process, considering they are the ones who are being most affected by this particular issue. In addition, transforming this body of work into a format that is more accessible to non-academic groups also represents important future work.

As became increasingly clear as this paper was researched and compiled, the SDOH model lacks an overall presence within infectious disease, climate change, and health policy realms. Specifically within our municipal context, its application appears to be limited to the identification of vulnerable groups only, accounting for why recommendations on infectious disease prevention are fixated on targeted adaptive measures for specific at-risk groups, as well as on public education. This is also reflected in the literature at higher levels of governance, from the limited surveillance data that is collected on infectious disease, to the recommendations put forth within climate change and health reports. Unfortunately, the SDOH model is not carried out fully within policy recommendations in the way that one would hope, and although certain at-risk subpopulations are recognized, those recommendations are limited to reactive measures so that attention is drawn away from the larger determinants which influence health disparities in our society. Malaria is an example of a disease that sits within both climate change and infectious disease discourses in which the SDOH model was highly explanatory. We must be open to the idea of expanding the application of the SDOH model to the realm of infectious

disease and all its ramifications if we are to begin to address not only disease prevention, but simultaneously prompt positive social change as well.

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